Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1958

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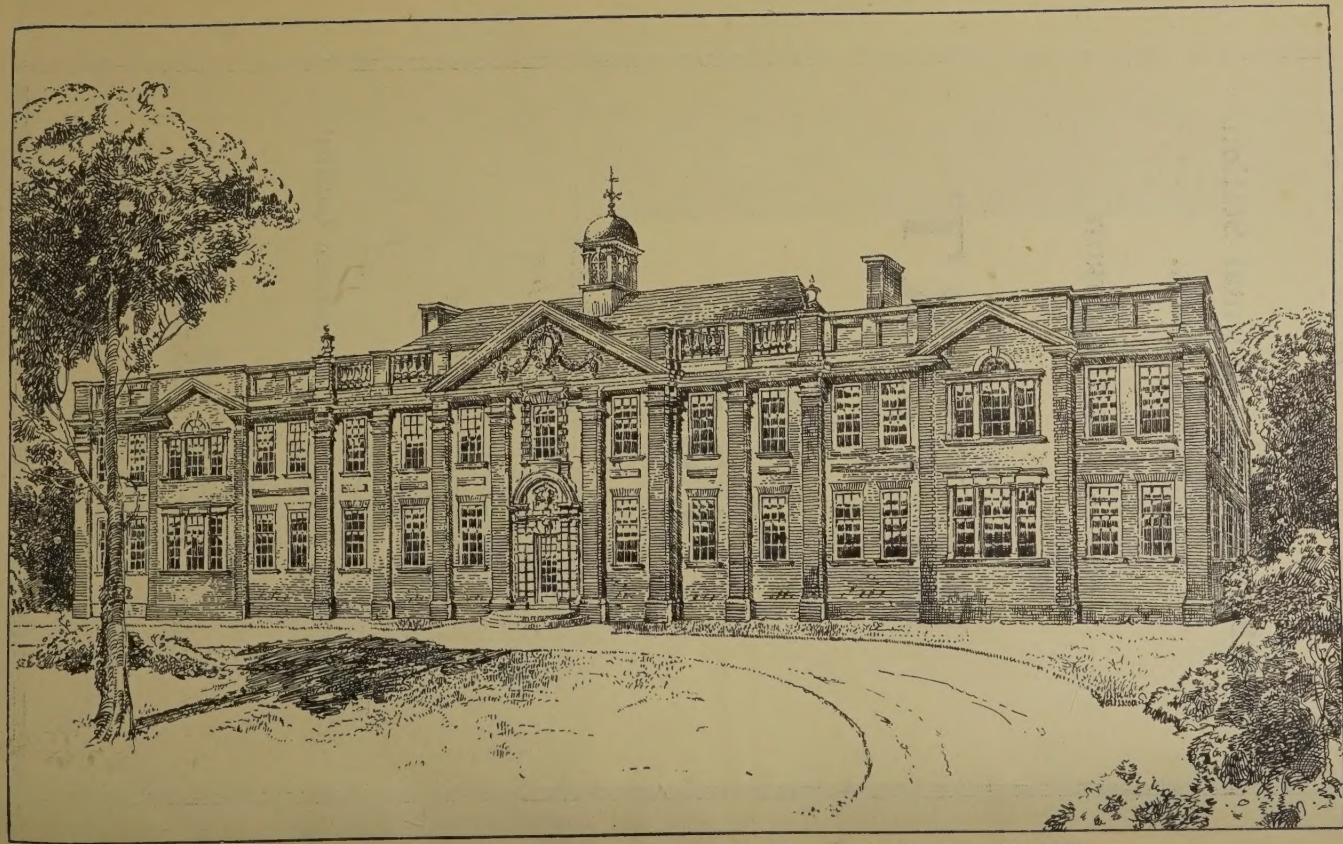

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1958

16 JUN 1959

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The following spent varying periods as temporary workers at Rothamsted during 1958:

Australia: MRS. EVE BOFINGER (Statistics), V. J. BOFINGER (Statistics), A. H. GIBSON (Soil Microbiology), J. LOVEDAY (Soil Survey), R. R. STORRIER (Soil Survey), R. J. SWABY (Soil Microbiology); **Belgium:** J. E. J. GH. TAHON; **British West Indies:** G. E. HODNETT (Statistics); **Ceylon:** L. H. FERNANDO (Botany), L. A. S. PERERA (Bee); **Eire:** L. FEELY (Bee); **France:** A. DELOBBE (Plant Pathology); **Germany:** H. G. FRITZSCHE (Soil Microbiology), E. MÖHN (Entomology); **Greece:** E. MASTRANDREOU (Insecticides); **India:** S. N. CHAKRAVARTI (Chemistry), G. M. DAS (Insecticides), C. V. GOVINDASWAMY (Plant Pathology), S. P. MITRA (Pedology), S. N. SINGH (Nematology), R. C. SINHA (Plant Pathology); **Japan:** M. KUSHIZAKI (Chemistry); **Malaya:** GLORIA LIM (Soil Microbiology), SIEW KEE NG (Pedology); **New Zealand:** W. C. CLARKE (Nematology), JEAN G. MILLER (Statistics), P. F. NOBLE (Physics), J. N. PARLE (Soil Microbiology); **Pakistan:** M. S. AHMAD (Physics), A. R. AZMI (Soil Microbiology); **Philippines:** H. T. BERGONIA (Plant Pathology); **Poland:** K. MICZYNSKI (Plant Pathology), Mrs. W. POTAPCZYK (Botany); **Rhodesia:** P. M. SYMMONS (Statistics); **Spain:** P. ARAMBARRI (Chemistry), C. CORRAL (Insecticides), J. RODRIGUEZ (Chemistry); **South Africa:** H. H. LOUW (Soil Microbiology); **Syria:** F. S. CHEBIB (Statistics); **Tanganyika:** P. J. LASCELLES (Statistics and Field Experiments); **U.S.A.:** V. H. DROPKIN (Nematology), B. S. MILLER (Entomology), M. SALOMON (Chemistry); **U.S.S.R.:** G. F. NAUMOV (Field Experiments), B. PLESHKOV (Chemistry), Y. A. RUSKO (Pedology); **West Africa:** B. O. E. AMON (Chemistry), C. M. H. ATKINS (Field Experiments), G. A. JONES (Statistics), C. L. M. VAN EYNATTEN (Statistics); **Yugoslavia:** V. JASNIC (Field Experiments), ANGELINA STOJKOVSKA (Chemistry); **British Isles:** P. BAKER (Dunholme Field Station), H. H. BLUEJACK (Chemistry), MARIE BROOKS (Plant Pathology), ANNE BULLOCH (Plant Pathology), S. F. BUCK (Statistics), JENNIFER M. BYRNE (Insecticides), I. A. CAMERON (Field Experiments), JANE A. COCHRANE (Entomology), R. CROPLEY (Plant Pathology), P. W. W. DABORN (Chemistry), BRENDA DODGSON (Insecticides), D. A. GOVIER (Plant Pathology), A. C. HASTIE (Plant Pathology), J. W. O. JEFFERY (Pedology and Chemistry), M. G. B. JOHNSON

(Soil Microbiology), Mrs. Lorna King (Statistics), Margaret Knight (Plant Pathology), D. S. Madge (Entomology), Rhona Morten (Bee), B. S. Mowl (Insecticides), P. W. Mueller (Plant Pathology), J. E. Nimmo (Statistics), J. M. Palmer (Chemistry), S. C. Pearce (Statistics), D. A. Perry (Plant Pathology), Anthea Potter (Nematology), J. L. Readshaw (Entomology), Joan Riches (Entomology), A. C. Rose (Plant Pathology), D. A. Rose (Physics), A. B. Spicer (Botany), W. S. Tallack (Entomology), M. J. Taylor (Botany), Anne Thomas (Bee), Norma P. Tilley (Entomology), Hilary Tompsett (Soil Microbiology), D. P. H. Tucker (Chemistry), Jean B. M. Tulloch (Entomology), G. J. Turner (Plant Pathology), D. Watson (Dunholme Field Station), Helen G. White (Botany).

SOIL SURVEY OF ENGLAND AND WALES

Head of Survey

A. Muir, Ph.D.(Edin.)

Deputy Head of Survey

D. A. Osmond, Ph.D.(Bristol)

Soil Surveyors

G. D. Ashley, B.Sc.(Sheffield)
B. W. Avery, B.Sc.(Reading)
E. M. Bridges, B.Sc.(Sheffield)
P. Bullock, B.A.(Birm.)
C. P. Burnham, B.A.(Cantab.)
B. Clayden, B.Sc.(Sheffield)
W. M. Corbett, B.Sc.(Edin.)
C. B. Crampton, B.Sc.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, B.A.(Cantab.)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(For.)(Edin.)
C. A. H. Hodge, B.Sc.(Wales)
J. M. Hodgson, B.Sc.(Lond.)
R. A. Jarvis, B.Sc.(Dunelm.)
D. W. King, B.Sc.(Lond.)
D. Mackney, B.Sc.(Bristol)
C. W. Montgomery, B.A.(Cantab.)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
A. J. Thomasson, B.A.(Bristol)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.) (In Northern Rhodesia)
G. F. M. Murdoch, M.A.(Edin.) (In Swaziland)
A. R. Stobbs, M.A.(Dunelm) (In Sierra Leone)

Chemists

C. L. Bascomb, B.Sc.(Agric.)(Reading)
Audrey M. Du Feu, B.Sc.(Lond.)
D. T. Prichard
H. H. Le Riche, Ph.D.(Lond.)

Cartographer

D. V. Jones

Assistant Staff

Pamela Ash, R. Ball, Mrs. Joan K. Foster, Mrs. Muriel Green, Mrs. E. Joyce Mitchell, Mrs. Mary R. Mitchell, Sylvia B. Reeves, E. M. Thomson, M. J. Wilson

Woburn Experimental Station

Officer in Charge

C. A. Thorold, M.A.(Oxon.)

Chemist

T. W. Barnes, M.Sc.(Lond.)

Assistant Staff

G. Pearce, Q. D. Pope

Dunholme Field Station

Head of Field Station

R. Hull, Ph.D.(Lond.)

Scientific Staff

S. N. Adams, D.Phil.(Oxon.)
W. J. Byford, B.Sc.(Lond.)
C. E. Cornford, Ph.D.(Lond.)
E. C. W. Dunham, B.Sc.(Edin.), Dip.Agric.(Cantab.)
R. A. Dunning, M.Sc.(Leeds), Ph.D.(Cantab.)

Assistant Staff

Eileen Anderson, G. N. Baxter, F. Ann Damms, Janet Hull, J. Iwanicki, Mrs. Joan Iwanicka, J. A. P. Marsh, Elizabeth H. Marshall, Mrs. Jean McLannahan, W. N. Moore, Marie D. Wolfe, R. W. Wright

Agricultural Research Council Unit of Plant Morphogenesis and Nutrition

Head of Unit

F. J. Richards, D.Sc.(Birm.), F.R.S.

Scientific Staff

W. W. Schwabe, D.Sc.(Lond.)
M. Bryant, M.Sc.(Lond.)

Temporary Workers

U. Pethiyagoda, B.Sc.(Ceylon)
S. Nachmony, M.Sc.(Jerusalem)

Assistant Staff

W. S. Biggs, Priscilla M. Dutton, C. Sinclair, Pamela J. Smith

The Commonwealth Bureau of Soils

Director	G. V. Jacks, M.A.
Consultant Director ...	F. C. Bawden, M.A., F.R.S.
Assistant Director ...	W. D. Brind, B.Sc.(Agric.)
Assistants	G. A. Greenwood, B.Sc. Mrs. M. Kathleen Milne, B.Sc. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Christine E. Dollimore, Rita E. Hough, Mrs. Iris Lindsay, Marguerita D. Payne

The Bureau, one of ten Commonwealth Agricultural Bureaux, was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the two work together closely. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by giving technical assistance when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. The Bureau keeps itself informed on soil workers and their research, throughout the Commonwealth. Each Government nominates one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. Technical information is usually given free to soil workers.

INTRODUCTION

Sir John Bennet Lawes was experimenting before 1843, but the Rothamsted Experimental Station dates its foundation from this year because he then started his long and fruitful collaboration with J. H. Gilbert and laid down the classical wheat experiment on Broadbalk field. Lawes died in 1900 and Gilbert in 1901: they were succeeded as directors by A. D. Hall (1902–12), E. J. Russell (1912–43), W. G. Ogg (1943–58) and F. C. Bawden (1958–).

Until 1904, when the Society for Extending the Rothamsted Experiments was instituted, the work was paid for wholly by Lawes, at first directly and from 1889 from the fund of £100,000 with which he endowed the Lawes Agricultural Trust. In 1906 Mr. J. F. Mason paid for a bacteriological laboratory to be built, and in 1907 the Goldsmith's Company provided an endowment of £10,000. The first public money came in 1911 from the Development Commission, and since then government grants have been made annually; now the work is largely financed by annual grants from the Agricultural Research Council.

For long the experimental fields amounted to only about 50 acres, which were worked from the Rothamsted Home Farm, but in 1913 this farm of 250 acres was rented by the Station and the first farm buildings were put up on the site of the present range. In 1934 the Manor House, Home Farm, the site of the laboratories and various other parts of the estate, were bought by the Lawes Agricultural Trust for £35,000, raised entirely from voluntary subscriptions. Since then some additional land and other houses have been acquired, and the total area now owned is 580 acres, of which about 300 are suitable for field experiments. In 1952 the Manor House was opened as a hostel for members of staff and visitors.

The need to do field experiments on a range of soil types was early recognized, and since 1921 experiments have been done at many places away from Rothamsted. The taking over in 1926 of the Woburn Experimental Farm, which had been run by the Royal Agricultural Society of England, allowed experiments to be made simultaneously on heavy land at Rothamsted and light land at Woburn. In 1947 work on diseases of sugar beet became a part of the station's activities, and this has now developed into the Dunholme Field Station, Lincoln, at which the pests and manuring of sugar beet are also studied.

Although a range of problems was studied before 1900, the work was mostly chemical, and only few workers were engaged. With increasing numbers of staff in the early 1900s, the activities also widened and Departments of Botany, Soil Microbiology and Physics separated from the original Chemistry Department before 1914, and soon after the end of the First World War new Departments of Entomology, Plant Pathology, Insecticides and Fungicides, and Statistics were started. Except for additional posts, for work on bees and on viruses and virus diseases, the Station's activities then

expanded little until the Second World War, when most Departments increased in size and others were added for Pedology (1945), Biochemistry (1947) and Nematology (1947). In 1946 Rothamsted also became the headquarters of the Soil Survey for England and Wales. From a total of 28 in 1912, the staff increased to 140 in 1943 and 471 in 1958. The Commonwealth Bureau of Soils, one of the ten bureaux that act as clearing centres for information on agricultural science, has been housed since its establishment in 1929, and the Agricultural Research Council Unit of Plant Morphogenesis and Nutrition, previously the Research Institute of Plant Physiology, has a laboratory and glasshouses at Rothamsted. The Station also accommodates visiting workers, many of whom use the special relationship with London University to register as internal students of the university for research degrees.

The building of laboratories, glasshouses and other ancillaries has roughly paralleled the growth of staff, but has always lagged behind, so that at least some of the departments are always overcrowded and the number of visiting workers that can be accepted is always much smaller than the number of applicants. Of the existing laboratories, the main block is the oldest and was opened in 1919; the North Building dates from 1924, the South Wing from 1940, the Nematology Building from 1947 and the West Building from 1955.

The Library

Until 1913, when Sir Henry Gilbert's books were given to the Station by his widow, the Library consisted almost entirely of Sir John Lawes's collection. It then grew rapidly in size and scope, until in 1917 it contained 10,000 volumes and in 1958 about 60,000 volumes. Its stock includes about 3,500 agricultural books published between 1471 and 1840, of which 13 are incunabula; 5,000 serial publications—1,700 of them current; 100 MSS. from the 13th century onwards, in addition to the Lawes and Gilbert papers; about 300 maps; and nearly 1,000 prints of livestock, mainly of the 18th and 19th centuries.

The following catalogues have been published: of serial publications (1954), of early agricultural books (1926, second edition 1940, supplement 1949) and of livestock prints (1958). The *Quarterly bulletin of the International Association of Agricultural Librarians and Documentalisis* (1956–) is edited and published in the Library.

GENERAL REPORT

F. C. Bawden

Sir William Ogg retired on 30 September. This is neither the time nor place to assess his directorship, but it is appropriate to record some changes during his period of office. When he came in October 1943 the total staff was 140, and when he left it was 471. Three new departments, Biochemistry, Nematology and Pedology, were formed, and the Station's activities were increased by the addition of the Soil Survey of England and Wales and of the work done for the Sugar Beet Research and Education Committee, which has developed into the Dunholme Field Station. The estate was increased by about 50 acres; other acquisitions were Rivers Lodge, which houses most of the Statistics Department, Rothamsted Lodge, which houses the Bee Department, and several smaller buildings. The West Block, which houses the departments of Entomology, Insecticides and Fungicides and part of the Plant Pathology Department, was the main new building, but others were a laboratory for the Nematology Department, one for the field experiments of the Chemistry Department and the leaf-protein work of the Biochemistry Department, a building for the electronic computer, an extension to Red Gables for a canteen, six farm cottages, additions to the farm buildings, and new glass-houses for the departments of Entomology, Plant Pathology, and Insecticides and Fungicides. Another major development, in which Sir William took great pleasure and of which he was justifiably proud, was the conversion of the Manor House into the magnificent hostel that adds so much to the Station's amenities.

Sir William was awarded the Rapphaele Piria Gold Medal of the Italian Chemical Society shortly before he retired, and soon afterwards was honoured again by being made an honorary member of the Royal Agricultural Society of England.

F. C. Bawden was appointed director from 1 October; he was succeeded as deputy director by F. Yates and as head of the Plant Pathology Department by P. H. Gregory. The expansion of work at the Dunholme Field Station to include the manuring and study of pests in addition to diseases of sugar beet was recognized by giving the Field Station the status of a department with R. Hull as its head.

Two deaths saddened the year. Lord Bledisloe, who was Chairman of the Lawes Agricultural Trust Committee from 1920 to 1924 and was actively interested in the Station for the rest of his life, died in July at the age of ninety. A. H. Bowden, a faithful and respected servant of Rothamsted for almost fifty years, was killed in a road accident in August. His was the only name of the existing staff that appears in the Station's first *Annual Report*, published in 1909. We deeply regret he did not achieve his ambition of a Golden Jubilee, at which it would have been our great pleasure to do him the honour he deserved.

H. V. Garner's many services to the Station and to agriculture were recognized by the award of the O.B.E. in the Birthday Honours List. Another event that gave great pleasure was the promotion of H. F. Barnes to the grade of Senior Principal Scientific Officer for his outstanding research. I. F. Long's winning a Darton Prize for his paper on " Instruments for Micro-meteorology " was also a notable achievement.

We gratefully acknowledge the generous support given us by the Rockefeller Foundation, which provided grants to expand the work on leaf protein, to buy an infra-red gas analyser and to pay for two members of the staff to visit the U.S.A.

Visits and visitors

Were science not already recognized to be international, our visitors' book and the travels listed in the departmental reports would show that it is. We welcomed visitors from most countries during the year, and the number of countries visited by members of the staff to attend conferences, symposia, to serve on committees or working parties, to give advice or to do some research was also considerable. The largest single influx of overseas visitors was for the successful colloquium on Research Methods in Soil Zoology organized by the Entomology Department immediately before the International Zoological Conference in London. Other visitors from abroad included Mr. Kedish Luz, the Minister of Agriculture, and Mr. Ben-David, the Assistant Director General, from Israel; Mr. Balaceanu, the Rumanian Minister in London; and Mr. Slavko Komar, Secretary for Agriculture of the Federal Executive Council of Yugoslavia. British visitors included the Minister of Agriculture, the Rt. Hon. John Hare, P.C., O.B.E., M.P.; the Chairman of the Agricultural Research Council, the Duke of Northumberland; and the Parliamentary Secretary to the Minister of Agriculture, Mr. J. B. Godber, M.P.

An exchange arrangement with the Russian Ministry of Agriculture allowed R. Cooper and A. Newman to work in Moscow for a year and brought Messrs. G. Naumov and B. Pleshkov here. A third Russian scientist, Mr. Y. Rusko, came as a British Council scholar. The compliment paid to us by the American Phytopathological Society in inviting five members of the staff to contribute to their Golden Jubilee Meeting was much appreciated.

The year's work

Whatever the weather, farmers are apt to complain, but there can be few years when complaints were more justified than in 1958. The year started well, and in May cereals promised bumper yields, but June, with twice the normal rainfall, altered the picture, and from then on things went from bad to worse. Hay was spoiled and cereals lodged badly; when combining was possible, the grain came in with a water content that taxed the new grain drier to the utmost. Fortunately, satisfactory methods for combining harvesting experimental plots of cereals and beans had been developed, for without these many experiments would probably have had to be abandoned.

The continued dull, wet weather favoured fungus diseases, and

potato blight was more severe than in human memory; repeated spraying with modern fungicides did little more than delay the epidemic. The only redeeming feature was the growth of the root crops, with sugar beet giving record yields and sugar content increasing unusually late in the year, but lifting was tedious and dirty. The soil continued wet, so that autumn ploughing was difficult and getting good seedbeds was impossible. Little winter corn has been sown, and rarely has field work been so far behindhand. Broadbalk typifies the autumn difficulties; it was ploughed in poor conditions, and drilling started early in December as soon as it became possible, but rain fell before it was finished, and at 31 December plot 2 was still not sown.

Soils and fertilizers

In some light soils organic matter seems necessary to maintain a structure, but at Rothamsted there is little evidence that it affects the growth of crops except through the supply of plant nutrients. Even with sensitive crops, such as carrots and beetroot, differences in soil structure seem to have any effect only during germination and for a little while after seedlings emerge. Results from the original three-course rotation experiment, which tested the effects of accumulated applications of straw and composted straw, suggested that the applications mainly affected yield by supplying potassium and withdrawing nitrogen from circulation. Results since 1952, when the experiment was redesigned specifically to test this point, confirm the earlier conclusion. Ploughing in straw at 53 cwt./acre decreased the yields of sugar beet and barley, neither of which responded to potassium in this experiment, by amounts compensated for by giving 0·2 cwt. nitrogen. Potatoes responded to both potassium and nitrogen, and straw, given with a compensating dressing of nitrogen, increased yield by the same amount as did its potassium equivalent given as potassium chloride. The effects of past dressings of straw also seem to derive solely from the residues of nitrogen and potassium.

The ley–arable experiment provides information on the way in which organic matter and plant nutrients change when old grassland is ploughed and when leys are introduced into an arable rotation. On Highfield, previously permanent grass and rich in humus, one-seventh of the organic matter was lost after 6 years of arable cropping, and the loss was not lessened by growing a ley for 3 of these years. On Fosters Field, old arable land containing much less organic matter than Highfield, 3 years under ley followed by 3 years arable cropping raised the organic matter by one-seventh, twice the increase obtained by ploughing in 26 cwt. of straw/acre annually for 18 years. In this experiment, too, responses of arable crops reflect the way treatments affect the amounts of plant nutrients in the soil, especially of potassium. Continued cutting and removing grass or lucerne seriously depletes reserves of this element, and yields of arable crops fall unless it is replenished.

Work on the failure of sugar beet, known as " Docking disorder ", emphasized the much greater importance of organic matter in some light soils. This trouble, characterized by slow growth caused by the main roots dying, was unusually prevalent in 1958, and invariably

occurred on light, alkaline soils containing little or no clay or organic matter. Mineral fertilizers do not control it, but organic manures and the taking of leys do. It may now become possible to test whether inadequate aeration is one cause of poor growth in these almost structureless soils, for methods that promise to give meaningful measurements on aeration were developed during 1958.

The value of reserves of potassium and phosphorus built up by manuring last century were tested by growing in 1957 and 1958 six crops on the Exhaustion Land Experiment, with and without new dressings of the two elements. The residual phosphate from manures applied between 1856 and 1901 was enough to give full crops of cereals, sugar beet and swedes in 1957, but not in 1958; in neither year was it enough for potatoes or kale. The residual potassium was enough for cereals, sugar beet and swedes in both years, but not enough for potatoes in either year or for kale in 1957. Even the land unmanured for over 100 years contained enough potassium for cereals, sugar beet and swedes in the conditions of 1957, but in 1958 swedes and beet responded to the fresh dressings. The long-term experiments at Rothamsted provide unique material for testing the value of fertilizer residues, and the experiments on Agdell and Barnfield are being adapted for this purpose.

Most current methods used to measure " available " phosphate are unsatisfactory with calcareous soils, and measuring the amount of exchange between soil phosphate and a solution of phosphate labelled with ^{32}P gave better results. "Available " potassium is measured by finding the amount that exchanges with another cation, usually ammonium, but the relevance of this to plant growth is open to question, because some of the potassium in many soils that is unexchangeable by this method can be used by crops. Grass growing in pots removed this type of potassium in amounts equal to those extractable by a hydrogen-saturated cation-exchange resin. Natural sources of potassium contain a constant fraction of the radioactive isotope ^{40}K, and measuring the radioactivity of soil promises to provide a method of estimating soil potassium less tedious than the chemical methods now in use. Results from chemical analyses and measurements of radioactivity agreed well, except with some soils that contain traces of other radioactive materials.

A series of fourteen experiments on the nitrogen manuring of spring-sown wheat and barley ended in 1958. Both crops gave profitable increases in yield with 3–4 cwt. " Nitro-Chalk "/acre at Rothamsted and up to 6 cwt./acre at Woburn. Wheat at both farms, and barley at Rothamsted, responded most when all the dressing was given before drilling, but at Woburn barley did slightly better with an early top dressing. Dividing the dressing, or giving a late top dressing, gave no benefit. Other experiments showed that heavy dressings of ammonium sulphate could be combine-drilled with the seed without affecting germination, and this method gave higher yields than broadcasting the fertilizer at sowing time. Except when lodging occurred, winter wheat responded better to nitrogen given in March than when given to the seedbed or in May. As nitrogen given in autumn was washed into the sub-soil by spring,

but nevertheless increased yields, inorganic nitrogen in the sub-soil must be used by wheat. Whether applied as solids or in solution, ammonium sulphate, ammonium nitrate, calcium nitrate and urea all greatly increased yields of old pasture and newly sown ryegrass. An aqueous solution of ammonia, however, damaged permanent grass and failed to increase yield; when applied before sowing ryegrass, it also increased yield less than did the other sources of nitrogen. All the fertilizers increased the amounts of water-soluble ammonium- and nitrate-nitrogen in grass, which may be important in affecting the health of animals that eat it.

Pedological studies on an increasing number of soils from at home and abroad make it increasingly clear that simple descriptions of soil profiles do not give a sound basis for soil classification. Valuable additional features are coming from examining thin sections of soils, a technique that promises to help elucidate soil genesis and to indicate relations between soils from different places. In some soils developed in loess-like material it provides evidence that clay has migrated down the profile and changed the structure of the profile. Mechanical analysis had previously suggested that soils from the Chiltern area commonly have a loess-like layer on the clay-with-flint deposits, and this was established by studying thin sections. Oxford Clay showed the same correlation between the content of trace elements and organic matter as previously found for Lias shales. A clue towards understanding the curious behaviour of molybdenum in " teart " soils may lie in the behaviour of this element in the presence of iron oxide. In water-logged soils molybdenum is strongly fixed to iron oxide, but is readily released on incubation with decomposing remains of plants.

Demands on the soil surveyors to examine experimental or demonstration farms, sites of open-cast mining, forestry land and to make surveys for town planners are considerable, but despite these, the primary survey made progress in eleven districts, and some sheets were finished. A soil map of the United Kingdom was prepared for inclusion in the map of the soils of Europe to be issued by the Food and Agriculture Organization; it will also be used by the Clarendon Press in a forthcoming atlas.

Soil microbiology

New chemicals are now constantly being introduced into agriculture, and it is important to know whether or not they will accumulate in the soil. Hence, to the older microbiological studies on nitrogen fixation and similar problems have been added tests with some of these new substances. Fortunately, most seem to be susceptible to microbial attack. The sex hormone stilboestrol, now widely used, disappears from soil, although rather slowly compared with the weed-killer, 2 : 4-D. A small dose of 2 : 4-D added to soil changes the flora to one better able to decompose it, and large doses increase the numbers of active bacteria. Species from three genera of bacteria that attack it in pure culture were isolated.

A considerable step towards understanding the anaerobic decomposition of cellulose was made by achieving the difficult task of getting a pure culture of a bacterium, provisionally identified as *Clostridium cellobioparum*, able to do this in pure culture. It breaks

down cellulose and produces organic acids, sugars, hydrogen and carbon dioxide, but not methane.

We reported in 1952 that clover grown on agar media in which clover seeds had already been germinated produced nodules quicker than when grown on fresh agar, and the effect was tentatively attributed to a stimulant secreted by the first plants. This interpretation is wrong; the effect occurs because the first plants remove traces of nitrate or nitrite from the media, which otherwise inhibit nodulation. The inhibition seems specific, because ammonium salts, asparagine and urea in similar minute amounts did not affect the formation of nodules. A start was made to estimate the importance of nitrogen-fixation in soil by free-living bacteria.

Crop growth

There is much evidence that differences in yield between individual crops of one kind depend on differences in leaf area, so substances that affect leaf area could affect yield. Gibberellic acid is such a substance, and last year it increased the yield of potatoes. However, although it consistently increases leaf area, it increases yield only within a restricted range of conditions. When potatoes were sprayed frequently with it, and particularly when nitrogen was limiting, photosynthesis was so affected that yield was decreased despite the increase in leaf area. Extracts of expanding French-bean leaves were found to contain a substance behaving like gibberellic acid on paper chromatograms and in its ability to accelerate the growth of discs of etiolated leaf. Its amount was correlated with the rate at which the leaves were expanding, so it seems to be a normal growth regulator of this plant.

An attempt is being made to measure the movement of carbon dioxide into a field crop by day from photosynthesis, and out by night from respiration, and to relate this with the yield of dry matter in the crop. The biological and physical measurements agreed reasonably well in August and September, but in October a flux from air to crop was detectable only in bright sunshine, and there is a suggestion that at some other daytime periods the crop may have been getting its carbon dioxide from the soil. Leaf areas were measured, so that the flux of carbon dioxide can be related to the size of the assimilating system; measuring the areas of leaves has become less tedious since an instrument has been developed that does it directly and quickly by a light-scanning method.

Seeds of wild oats persist under temporary leys much longer than when arable crops are grown; many seeds survive for more than 4 years, so short-term leys are evidently no answer to heavy infestations. No evidence was found to support the idea that couch grass exudes substances into soil that are toxic to crops, although it was confirmed that dried roots and rhizomes contain substances that inhibit germination and growth of seedlings. The seventh consecutive wheat crop on section 1a of Broadbalk, which has been returned to continuous wheat and is sprayed with weed-killers, looked much better, particularly on plots 3 and 5, which get no nitrogenous fertilizer, than did the second wheat crop after fallow on section 1b. These plots are heavily infested with leguminous weeds; killing these in spring probably led to the response, which

almost doubled the yield of grain. Only time will tell whether this effect will continue, or whether the repeated use of weed-killers on section 1a will eliminate leguminous weeds and make yields of plots 3 and 5 decline from lack of nitrogen.

Biochemical work on the blackening of potato tubers supported the idea that the pigment responsible is a complex of ferric iron and dihydroxy phenols, produced when colourless ferrous complexes oxidize in air. Blackening is also affected by the amount of citrate in tubers; this and other substances that form colourless iron complexes prevented blackening when added to water in which the tubers were boiled. Potatoes from Woburn blackened less than those from Rothamsted, where blackening varied more with the kind of manuring.

Methods of extracting and preparing leaf protein for human consumption were improved, and encouraging yields were obtained from a range of plants; of spring-sown cereals, oats were the most productive and gave 471 lb. of protein/acre when cut in June. However, plants that now contribute nothing to human nourishment may find a use through this process, for nettles growing wild, except for a small dose of fertilizer, yielded 546 lb. of protein/acre.

Pests and diseases

The year favoured fungus diseases but not pests; virus diseases also spread much less than in 1957, for although early in the season it seemed that aphids might again be abundant, the weather later turned against them, and their predators were also plentiful. After the great losses from sugar beet yellows in 1957, a regular survey of the crop was organized from Dunholme, and warnings of the need to spray were issued when aphids averaged one per four plants in any district. As a result, 100,000 acres were sprayed, and in September yellows was much less prevalent in sprayed than in comparable unsprayed crops. In some districts yellows was not serious enough to affect yields, but in others spraying increased yield by amounts up to 5 tons of roots/acre.

It was reassuring to find from the health of seed tubers saved from the 1957 potato experiments that, despite the unprecedentedly early and heavy aphid attacks that year, spraying with insecticides completely stopped the spread of leaf roll. Spraying did not prevent the spread of rugose mosaic, but this, fortunately, is less important than leaf roll. The practical value of insecticides in controlling the common virus diseases of sugar beet and potatoes now seems established, and preliminary experiments suggest that applying them to beet seed and potato tubers, or to soil at planting time, may protect crops soon after they emerge and add to the benefits gained from spraying the growing crops.

Organophosphorus insecticides are generally considered to act by affecting cholinesterases, and most of them do affect these enzymes. However, that it may not be the only way all of them act was suggested by the fact that poisoning house flies with " Diazinon " had no effect on the cholinesterase activity of their brains. The mechanism whereby flies become and remain resistant to " Diazinon " seems to differ with different strains: one resistant strain remained resistant from generation to generation without being continually

exposed to the poison, whereas another remained resistant only when each generation was exposed. Continuing work on pyrethrins and related compounds gave further information on the relation between chemical structure of molecules and their insecticidal activity, and suggested that crude extracts of pyrethrum contain insecticidal substances other than those previously recognized. Some substances were found to enhance the valuable " knock-down " action of pyrethrins.

Much evidence was obtained compatible with the idea that infection by tobacco mosaic virus entails the dismantling of the virus particles and the separation of the nucleic acid from the protein. The protein undoubtedly stabilizes and protects the nucleic acid, and differences between the susceptibility of different plants to infection are conveniently explained by postulating differences in their ability to inactivate the nucleic acid when it becomes free; but the explanation remains in doubt until it is proved that infecting particles are dismantled in host cells. The action of some of the agents found to inactivate fragments of tobacco mosaic virus was difficult to interpret if the minimal infective unit has the simple structure of a sequence of nucleotides now generally assigned to nucleic acids. Infective fragments consisting mainly of nucleic acid were also obtained from viruses other than tobacco mosaic. Tobacco rattle, a soil-borne virus, resembles tobacco mosaic virus in being a hollow rod and, possibly, in having its protein units spirally arranged along its long axis. Rods of two lengths occur in infected plants; both are nucleoprotein, but only the longer ones are infective.

The common virus disease of cereals, yellow dwarf, which is particularly damaging in oats, seems to be caused by at least two viruses, each of which occurs in strains of different virulence. Leafhoppers infected with wheat striate mosaic virus produced fewer young than uninfected ones, and many of the eggs they laid failed to hatch; this is the first unequivocal evidence of a plant virus harming the insect that transmits it. Further evidence was obtained that strains of potato virus Y normally not transmitted by aphids can become transmissible as a result of multiplying in plants simultaneously infected with strains that are aphid-transmitted.

In the favourable conditions for spread of potato blight there was little difference between the dates at which four potato varieties, reputedly of different susceptibilities, became defoliated. However, varieties did differ in the extent to which their stems became invaded by the fungus and to which lesions on their leaves produced spores. Blight outbreaks are generally thought to start only from lesions that develop on shoots produced from infected tubers, but in this wet year the fungus also spread through soil from diseased tubers that produced no shoots and directly infected the lowest leaves of nearby plants growing from uninfected tubers.

Eyespot and take-all of cereals were also unusually severe in 1958. The high incidence of eyespot made lodging even more serious than it otherwise would have been and contributed to the low yields; on the Rothamsted six-course rotation experiment, for example, the wheat was 100 per cent infected, lodged early, and the yield was 18·7 cwt./acre compared with the previous 20 years' average of 30·4. Take-all was particularly severe when winter

wheat followed another wheat or barley crop, but was negligible after oats. The incidence of mildew on Broadbalk was clearly correlated with manuring and was least on plots getting potash as well as nitrogen and phosphate.

As the growing of peas increases, fusarium wilt becomes increasingly common and important. Field trials with ninety pea varieties on infested land showed that more than half of them, including many that are popular and widely grown in the United Kingdom, are highly susceptible. Some of these are described as resistant in other countries, suggesting we have strains of the fungus not yet in those countries. Fortunately, many varieties were resistant, and there seems ample material for the plant breeders to use in producing desirable varieties resistant to wilt. The fungus, however, varies, and no single variety can be relied on to resist the disease indefinitely.

Most kinds of pathogens show this type of variability, nematodes no less than fungi. Strains of potato-root eelworm that infect potatoes at first thought to be resistant are now known to occur commonly, and some beet eelworms develop in *Beta patellaris*, previously considered not to be a host of this pest. Thus, although resistant varieties should be sought, this cannot be relied on to control eelworms, and other ways of decreasing damage are being sought, such as by varying crop rotations, or methods of cultivation, and by soil treatments. Much new information about the factors affecting the movement of eelworms through soil and over plants was obtained, and considerable progress was made in isolating the substance exuded by potato roots that causes cysts of the root eelworm to hatch. The " hatching factor " was consistently correlated with a single fluorescent spot on chromatograms, and although the chemical composition of the " hatching factor " was not determined, some progress was made towards its identification.

Bees

Improving methods for assaying " queen substance " led to much new information about this important material. It is produced in the queen's mandibulatory glands, from where she apparently distributes it over her body while grooming and makes it obtainable by her workers. It inhibits workers from raising queens, and, when given to queenless workers, inhibits the development of their ovaries. Queens that have been superseded or have swarmed from uncrowded colonies contain less of the substance than those in colonies of the same size with only one queen, a clear suggestion that the substance could have important applications in colony management. Workers at the National Institute of Medical Research are collaborating with us to try to identify the active material in queen substance.

No evidence was found to support the claims of workers in other countries that bees can be directed to pollinate given crops by incorporating pollen from these crops in nectar fed to the colonies.

Observations in years with very different nectar-flows show that acarine disease is inversely correlated with amount of nectar. Antibiotics suppressed European Foul Brood, and fumigating comb with formaldehyde or acetic acid promises to be valuable in freeing it from contaminating bacteria.

The increasing use of insecticides on crops is obviously dangerous to bees, and tests on dead bees sent to us indicated that some had been killed by parathion, some by DDT and some by arsenic. "Metasystox" was not found in bees suspected as having been killed by it, but this may be because the insecticide had decomposed.

Statistics

Statistical work again was concerned with far more than Rothamsted's experiments, and results were analysed for many other research stations and organizations, both at home and in various Commonwealth countries. A major task was the summarizing of 230 fertilizer experiments, each of twenty-seven plots, made on rice farms in Bihar, India. The survey of fertilizer practice was continued and extended, and other large surveys organized were of the growing of maincrop potatoes and of diseases in dairy cows. The enormous amount of computation involved in analysing the results from experiments and surveys is possible only by the electronic computer and by steadily improving its performance and hours of operating. This year the number of variates analysed was one-third more than in 1957, and the number of experiments analysed was nearly five times as many as in 1951.

PHYSICS DEPARTMENT

H. L. Penman

Before taking up an appointment with a soil mechanics unit of the Commonwealth Scientific and Industrial Research Organization of Australia, Margaret Dettmann left the department in June to work for a few months at the Institut für Bodenbearbeitung in Brunswick, Germany. Mr. H. D. Orchiston and Mr. P. F. Noble returned to New Zealand early in the year. Dr. M. S. Ahmad, of the Geophysical Institute, Quetta, West Pakistan, was with us for two months. Mr. D. A. Rose came in October as an Agricultural Research Council scholar for a period of two years.

Margaret Dettmann and J. A. Currie took part in a discussion on Soil Structure in Ghent, Belgium; I. F. Long paid a four-day visit to the laboratory of Dr. R. Geiger in Munich, Germany, during which he gave a lecture on our work; H. L. Penman, at the invitation of the East Africa High Commission and the Empire Cotton Growing Corporation, spent a month in East Africa studying water problems in Kenya and Uganda.

A Darton Prize of the Royal Meteorological Society was awarded to I. F. Long for his paper on micro-meteorological instruments.

Soil Physics

Electrical charges on clay

Previous work showed that kaolin possesses a permanent negative charge; this can be measured by changes in pH and electro-osmotic behaviour as the negative charge is progressively reduced by adding cetyl trimethyl ammonium bromide (CTAB), but only when deflocculants are present. A lower value of the effective charge is obtained in the absence of deflocculants. It has now been found that both the lower charge and permanent negative charge can be obtained from a single experiment, without adding deflocculants, by measuring the change in electrical conductivity of a kaolin suspension as increasing amounts of CTAB are added to it. When the change in conductivity per unit increment of CTAB is plotted against the total amount of CTAB added, the points lie on smooth curves, almost linear, with distinct changes in slope at characteristic values of added CTAB, values that are reproducible and are regarded as indirect measurements of the lower and upper limits of the charge mentioned above.

The probable explanation depends on the ideas put forward a year ago, in which it was suggested that the standard pre-treatment with an acid KCl solution, followed by washing with distilled water, leaves the crystals under a very great electrical stress: some decomposition of the crystals takes place and complex ions containing aluminium are released from the lattice. These ions can, of course, take part in the electrical balance of the clay system, but do not dissociate from the clay surfaces (so forming a Stern layer) as do

the more mobile K ions. Consequently the permanent charge is balanced by two classes of ions, mobile and non-mobile. The direct measurement of the charge in the electro-osmotic test is a measure of the mobile ions, i.e. the lower limit of the charge, and it is only when the complex ions are made mobile by the addition of deflocculants that the full negative planar charge can be measured.

In phase I of the conductivity measurements the K^+ ions are replaced by CTA^+ and the effective planar charge is reduced to zero. In phase II the complex ions are replaced by CTA^+, but as they move slower than K^+ in an electrical field the transition between phase I and phase II is detected. In phase III (all K^+ and all complex ions having been replaced by CTA^+) the change in electrical conductivity records the addition of CTAB without exchange, though part may be adsorbed by the kaolin. The advantage of the conductivity experiment is that it shows that the complex ions are replaced by CTAB in phase II.

As has been mentioned, once the mobile K ions have been replaced the effective charge is zero. If, in phase II, the complex ions were completely exchanged by CTA^+, then the planar charge would remain zero until the start of phase III. In the direct measurement of the charge by the electro-osmotic test, the transition between I and II is measured as the lower limit of the charge; this means that some CTAB is adsorbed without exchange, which may be an effect of mutual attraction between the long hydrocarbon chains, or of a direct adsorption by the kaolin.

The conductivity tests also throw some light on the effect of heating kaolins to 300° C.: the same three phases are obtained as for the acid-treated kaolins. Consequently the effect of heating is again a decomposition of the crystals; and an apparent reduction in cation exchange capacity at pH 7, as determined by the use of N ammonium acetate, is attributed to the difficulty of replacing the complex ions by NH_4^+. The conditions for replacement are more favourable in a conductivity experiment, since distilled water should give the greatest possible expansion of double layers, and CTA^+ has a greater replacing power than NH_4^+. (Cashen.)

Soil structure field experiment

Two blocks are in the third phase of a sequence: 4 years' ley or fallow: 3 years' test cropping: return to ley or fallow. No visible differences were observed this year in the growth of the crops.

The third block carried its third set of test crops since it was ploughed out from grasses in 1955. In 1956, cropped with beetroot and carrots, and again in 1957, cropped with carrots and beetroot (plots interchanged), the indications were that any structural differences resulting from previous cropping were having their effect during germination and for a short period after emergence. The 1958 test was, therefore, made a germination test. Barley, sugar beet and kale were sown successively at the ends of March, April and May, each crop being allowed to germinate and develop for a short period before being extirpated with the minimum of soil disturbance to make room for the next. All plots received a basic dressing of fertilizer (10 : 10 : 18) at 10 cwt./acre.

Low soil temperatures in April delayed emergence of the barley,

but all plots were equally affected. Counts of coleoptiles per unit row length a month after sowing showed significantly higher numbers on those plots that had carried ryegrass and timothy (with simulated grazing) in the years 1951–55, non-significantly higher numbers on those plots that had carried ryegrass, timothy and cocksfoot cut for hay during the same period. Previous test cropping showed a small effect. Where the order was ley, carrots, beetroot, barley, the counts were higher than for ley, beetroot, carrots, barley, especially where the ley had been grazed. The carrot/beetroot order had no effect on former fallow plots, and in general the barley emergence on these plots was as good as on the best of the former grass plots.

Short heavy showers in a mainly dry period after sowing the sugar beet caused dispersion of the surface soil, which then dried to produce a thick crust on all plots. Germination counts three weeks after sowing showed no differences between plots.

The kale germinated in a wet period during which the surface soil was frequently puddled. As for the barley, the sequence ley, carrots, beetroot, kale gave a better emergence on the former grass plots than the sequence ley, beetroot, carrots, kale.

Measurements of soil stability, soil water and soil temperature showed no differences corresponding to observed differences in emergence counts. (Currie.)

Soil aeration

The gaseous exchange between the soil and the atmosphere is mainly a diffusion process in which the gas molecules concerned (O_2 and CO_2) have to find their way through a system of tortuous channels of irregular and varying cross-section. It is easy to predict that the interchange rate will increase as the air-filled pore-space of the system is increased, and a laboratory study (H. L. Penman (1940), *J. agric. Sci.*, **30**, 437–462) showed that for dry granular solids the relation $D = \frac{2}{3}SD_0$ held in the range of pore-space $0 < S < 0{\cdot}6$, where D_0 is the coefficient of diffusion in free air. Subsequent work elsewhere has sometimes confirmed this relation: and as frequently contradicted it, particularly when the material was not dry. A thorough study of the effect of water in sealing off parts of the pore-space, in increasing tortuosity and in reducing cross-sectional area available for diffusion seems worth while; but it must be thorough, for there are already too many first approximations available. Progress so far has been satisfactory. Hydrogen is being used as the test gas, partly because it is not a normal component of soil air or atmospheric air. A simple technique, based on thermal conductivity, has been devised to measure the concentration of hydrogen in a small volume, and this is accurate and reproducible over the whole range 0–100 per cent. Laboratory measurements of diffusion in dry porous media have produced results in general agreement with the equation given above, and an estimate of the value of D_0 for hydrogen into air agrees very well with one of the standard values of this " constant ". With this reassurance that the technique is adequate, measurements are now being made on wet materials.

In parallel with the experimental work, considerable thought is

being given to the theoretical aspects of the problem. Until we know why diffusion rates are affected by soil geometry and water content it will be difficult to suggest how soil management might be modified to produce a desired condition. (Currie.)

" Docking disorder "

Physical measurements have been made on soils from good and bad sites where " Docking (or Docking-type) disorder " is found. (See below, p. 195.) (Currie.)

Soil water

Field checks of the neutron-rate meter monitor have not been discouraging. From early June the soil was never far from field capacity, and all the observations were at the top end of the range. By the end of the summer the source had decayed so much in power that the rate-meter circuit was inadequate, and a counter unit is being added to the monitor so that both instantaneous rates and total counts per standard time can be determined. (Long.)

The thermocouple method of measuring relative humidity in the range 95–100 per cent (last referred to in *Rep. Rothamst. exp. Sta. for 1956*) has now become a routine laboratory method, and has been used by other members of the station to determine soil moisture tension (pF), and the osmotic potential of solutions. A full description has been published (1.4, p. 236 below). It takes several days for very wet soils to come to equilibrium with the air in the small test chamber, and as during this time hourly temperature changes must be maintained within $\pm 0{\cdot}001°$ C., the useful upper limit of the equipment is 99·98 per cent relative humidity, corresponding to a tension of 3 metres of water, or pF = 2·5. As a dozen soil samples, all at different water contents if desired, can be handled simultaneously, the moisture characteristic curve of a soil in the range pF 2·5–4·8 can be obtained more quickly than by the standard techniques currently available. The curve for Great Field soil, determined in the new way, agrees well with the curve for soil from a nearby site previously obtained by centrifuge and freezing-point techniques. (Monteith and Szeicz.)

Agricultural Meteorology

Micro-meteorology

Considerable progress has been made with the analysis of the temperature, humidity and ventilation data collected in spring wheat during three summers 1955–57. A detailed survey will be given in a later report when digestion is more complete, but the type of information that is emerging includes: the persistence of high humidity inside the crop; the conditions that lead to active condensation on the crop, and the sources of this dew; the relation between air movement inside the crop and that over the crop; heat transport from the crop, upward and downward, water vapour transport from the crop; and, perhaps of most general importance in trying to specify a " crop climate ", the existence of detectable differences, persisting for hours at a time, in the temperature and

humidity at the same level above ground at sites only a few feet apart horizontally.

The field work in 1958 has been on sugar beet, and the disposal of the equipment much the same as for the wheat. Vertical profiles of temperature, vapour pressure and air-flow have been recorded continuously for a period of six months in the middle of the experimental area, and also at the south-west and north-east corners to get a picture of horizontal variations. Soil temperatures have been recorded from 0 and 24 cm. depth, in the rows and between the rows, and leaf temperatures, too, have been measured. Cursory examination of the records shows that they carry plenty of interest. As examples: (i) there have been many day-time periods in which the humidity under the crop has remained close to saturation (not surprising in the summer of 1958), and the vapour-pressure gradients have indicated a downward movement of some of the transpired vapour to the soil surface. (ii) The broad-leaved crop has shown much greater night cooling on clear nights than we ever observed in wheat, but daytime leaf temperatures have not shown any correspondingly greater day maxima. (iii) As recording was maintained until early December, some frost periods were included. Leaf temperature can go down to −2·5° C. before freezing occurs, when it rises instantaneously to 0° C., and thereafter progressively falls.

The general observations on the frequency of occurrence of dew (summarized in publication 1.2 of the 1957 report) have been maintained. It is estimated that dew occurred on 78 nights from July to October inclusive, but only on 30 did it persist until 0900 G.M.T., the time of official observation and recording. (Long.)

Heat and water balance

Sugar beet was grown on the field balance described in the 1957 report, in the middle of the area over which Long's observations are made. Evaporation, net radiation exchange and heat flow in the soil were recorded continuously throughout the growing season, characterized by wet surface soil except in the early stages of the crop. During seedling stage the rate of evaporation—mainly from the soil—was about half of that from the 6-foot-square open water tank nearby, but for the period July–October, when the leaves completely shaded the ground, crop transpiration exceeded tank evaporation by 6 per cent. At no time did the soil-moisture deficit exceed 4 cm., whereas under wheat in 1957 it reached 11 cm. In comparing the two seasons there is thus a contrast in crop and a contrast in weather.

As part of the study of crop contrasts measurements have been made, for different crops, of the reflexion of short-wave radiation using radiometers constructed at Rothamsted, and of the emission of long-wave radiation using a Linke–Feussner radiometer kindly lent to us by Professor P. A. Sheppard of Imperial College, London. Seasonal variations in the short-wave reflexion coefficient of sugar beet, wheat and potatoes have been related to leaf area, and it has been found that when leaves completely shade the ground the coefficient is 0·26, independent of crop type or visible colour. A lower value for spring wheat (0·21) is attributed to incomplete cover, and a value of 0·27 for winter wheat (in May) suggests that this crop had

by then produced more leaf than the spring-sown crop ever attained. Measurements of reflexion coefficient may give useful estimates of leaf growth without laborious sampling.

The long-wave radiation measurements lead to a radiative leaf temperature, accurate to about $\pm 1°$ C., and it is doubtful, at least in full sunlight, whether direct measurement can achieve anything much better. In such bright sunshine the order of increasing surface temperature was open water, grass, sugar beet, ripe wheat, with a range of 7° C., equivalent to about 10 per cent range in net radiative loss. For the green crops, actively transpiring, the range is smaller, and with their short-wave reflexion coefficients equal, it seems unlikely that there are any significant differences between the values of net radiation received by such crops. The sharing of this energy among transpiration, heating of the air and heating of the ground is being studied as the wheat (1957) and the sugar beet (1958) data are being analysed. (Monteith and Szeicz.)

Radiometry

The Kipp solarimeter on the laboratory roof now feeds into a potentiometer-type recorder, which provides simultaneously a continuous pen record of intensity and an integrated total in calories/sq. cm.

With this as standard, other methods of integration of solar radiation are being compared, using instruments kindly loaned to us by their manufacturers. These include a photo-cell unit, working into an electrolytic meter (developed at the National Institute of Agricultural Engineering and now made by Megatron Ltd.), and the Gunn–Bellani distillation-type gauge (made by Baird & Tatlock (London) Ltd.). Over periods of several weeks there is a good linear relation between daily radiation totals (Kipp) and the illumination as measured by the photo-cell, but the response of the Gunn–Bellani gauge is non-linear. Experience in East Africa shows that a linear regression to convert distillation readings to radiation can be used with confidence: our greater range of radiation intensities, and larger day-to-day variations in totals are apparently taking the instrument outside its best working range.

For field use, the development of small sensitive radiometers continues. The latest has a circular sensing unit about 2 cm. diameter, consisting of 32 copper—constantan junctions that give an output of 15 mV for 1 calorie/sq. cm./minute (midday, midsummer value for a fine day). Performance is good, apart from a suspected dependence of sensitivity on cloud amount. (Monteith and Szeicz.)

Measurement of carbon dioxide flux

A very generous grant from the Rockefeller Research Foundation, followed by rapid development work by the manufacturers, produced for us within a few months an infra-red gas analyser with a nominal range (on high sensitivity) of -5 to $+5$ parts/million CO_2 about an (arbitrary) zero near 300 p.p.m. This was in use from August to October over the sugar beet, and has given records of the diurnal changes in CO_2 concentration differences over a height interval of 25 cm. (10 and 35 cm. above the crop). In August and

September the daytime gradient of concentration was downward (CO_2 moving from air to crop) as the crop assimilated: by night it was reversed as CO_2 was released to the atmosphere by respiration. In October, however, the flux of CO_2 from air to crop was detectable only in bright sunshine, and there is some evidence that in other daytime periods the CO_2 requirements of the crop were obtained from the soil.

Quantitative estimates of flux are being calculated from the measured gradient and an estimated transport constant derived from weather measurements on the same site, and these estimates of " growth rate " will be linked with other meteorological elements (radiation, temperature, to name two). Over longer periods there will be comparison with the dry-matter increments obtained from direct sampling by the Botany Department (see p. 80), and from such a comparison it may be possible to estimate CO_2 production by soil micro-organisms. (Monteith and Szeicz.)

Irrigation at Woburn

Once again the summer weather pattern has been unkind, with a dry, rather cold spring and a wet summer starting in mid-May and persisting throughout growing and harvest periods except for a fortnight in mid-July. The result was that plots irrigated before the beginning of June were then brought to field capacity, and it is estimated that during June and July the rainfall equivalent of 4 inches of water passed down through the profile of the irrigated grass plots, presumably removing nitrogen in the process. Details

Woburn Irrigation, 1958

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield, cwt./acre	
Grass	28 Apr.–29 Sept.	14·2	—	ON_2	74	Dry matter 8 cuts
				ON_4	88	
		14·2	3·8	CN_2	76	
				CN_4	88	
Sugar beet	28 Apr.–29 Sept.	14·2	—	ON_1	42	Sugar
				ON_2	50	
		14·2	1·7	CN_1	38	
				CN_2	54	
Spring wheat	28 Apr.–1 Sept.	11·9	—	ON_1	24	Grain
				ON_2	28	
		11·9	1·5	CN_1	23	
				CN_2	25	
Beans	28 Apr.–29 Sept.	14·2	—	OD_1	18	Grain
				OD_2	17	
		14·2	1·0	CD_1	19	
				CD_2	17	

(Penman and Barnes.)

of the individual cuts on the grass appear in the Woburn report (p. 188) and the results of the third cut (24 June) and the fourth (15 July) are of some interest. By 24 June the irrigated plots had about 1·25 inches of leaching, and the control plots none; the nitrogen response on the former was negligible, but was very good on the

latter. By the time of the fourth cut, the irrigated plots had a further 1·75 inches of leaching, and the control plots 1 inch, and neither showed any response to nitrogen.

The table gives, as usual, a statement of responses to full irrigation designed to keep the plots near field capacity (C plots) at two levels of nitrogen (N_1 and N_2, or N_2 and N_4 for grass, dung for beans).

CHEMISTRY DEPARTMENT

G. W. Cooke

G. H. Owen left in January to take a post at the University College of North Wales. T. Z. Nowakowski joined the staff in April, M. St. J. Foale in May and Miss Marie Blakemore in August.

J. M. Bremner returned after a year in the U.S.A. on a Rockefeller Foundation Fellowship. A. C. D. Newman went to Russia in July, where he will spend a year working mainly at the University of Moscow under an exchange scheme organized by the Russian Ministry of Agriculture, the British Council and the Agricultural Research Council. His place has been taken by Dr. B. P. Pleshkov of the Timiryazev Agricultural Academy, Moscow. B. Benzian and J. K. R. Gasser attended a meeting of Commissions II and IV of the International Society of Soil Science in Hamburg in August. F. V. Widdowson studied field-experiment techniques and results at experimental stations in Denmark, Sweden and Norway. G. W. Cooke attended the Third Congress of the Association Internationale d'Études Phosphatières at Biarritz in October and gave two papers.

P. W. W. Daborn of the Forestry Commission returned to the Commission's Research Station in August. J. W. O. Jeffery of the Colonial Research Service left in November for Sierra Leone after receiving training during the year in field experimentation and soil fertility work. D. P. H. Tucker joined the department in October for similar training. B. O. E. Amon (Nigeria), P. Arambarri (Spain), H. H. Bluejack (Nigeria), S. N. Chakravarti (India), M. Kushizaki (Japan), J. Rodriguez (Spain), M. Salomon (U.S.A.) and Miss A. Stojkovska (Yugoslavia) all worked in the department during the year.

K. Shaw, now of the National Agricultural Advisory Service, obtained the Ph.D. Degree of London University for work carried out in the department.

Soil Organic Matter

Organic matter binds soil particles together and increases aeration, drainage, root range and water-holding capacity. Some of these important effects are not easily achieved in other ways. The practical value of increasing the supply of organic matter in a soil is difficult to define because the physical effects of improved soil condition on plant growth depend on the type of soil, the season and the kind of crop; in addition, the changes in nutrient supply, which are linked to changes in organic matter, themselves affect crop growth, and it is rarely possible to separate and measure physical effects alone. Organic matter may be increased by applying organic manures or waste materials; as these also supply plant nutrients, organic manuring increases both the physical and chemical sides of soil fertility. Soil organic matter is also increased by growing grass continuously, but when the grass is cut and carried

away so many plant nutrients are removed that chemical fertility is depleted although organic matter reserves, and soil condition, may be improved by the grass. Some of the factors that affect the balance between additions and losses of organic matter are being investigated together with the changes in plant nutrient supplies that are involved.

Changes caused by leys and by arable cropping

Organic matter accumulates in soils under temporary or permanent grass and decreases when land is ploughed from grass for arable cropping. Changes of this kind are being measured in the soils of the ley–arable experiments on Highfield and Fosters Field at Rothamsted. The two fields provide an interesting contrast, as Highfield was ploughed from very old pasture when the experiment was started whereas Fosters had long been in arable cropping. Both experiments test 3-year rotations, a 3-year ley as treatment phase being followed by 3 years of arable test crops (wheat, potatoes and barley). Table 1 gives the organic carbon determined after one 6-year cycle, the losses from cropping (relative to the organic matter status under permanent grass on Highfield) and the gains from leys (relative to the organic matter level under permanent arable cropping on Fosters).

TABLE 1

Amounts of organic carbon in the soils of the Rothamsted ley–arable experiments

(Measurements refer to the surface 12 inches of soil)

	Highfield		Fosters Field	
	Carbon, %	Loss (relative to permanent grass), %	Carbon, %	Gain (relative to arable), %
Continuous treatment with				
Permanent grass ...	3·22	—	—	—
Reseeded grass	3·02	0·20	1·68	0·26
All-arable rotation ...	2·74	0·48	1·42	—
Ley–arable rotation, 3 years arable crops and				
3 years of lucerne ...	2·75	0·47	1·56	0·14
3 years of grazed ley ...	2·83	0·39	1·60	0·18
3 years of cut grass ...	2·78	0·44	1·64	0·22

On Highfield about one-seventh of the organic carbon present when the land was ploughed from grass was lost during 6 years of arable cropping; on this highly organic soil the rate of loss was much the same when 3 of the 6 years of arable crops were replaced by lucerne or by a grass–clover ley. At the lower level of organic matter on Fosters Field the introduction of three years of ley increased the carbon content by 10–15 per cent. Reseeded grass, grown for the whole of the 6-year period on Fosters, increased the original carbon content of the soil by nearly one-fifth. The results illustrate both the rapid loss in organic matter when grassland is

ploughed for arable cropping and the slow increase when old arable land is sown to grass or is cropped with a rotation including a ley. (d'Arifat and Warren.)

On light soils continuous arable farming may decrease organic-matter levels so much that some crops do not succeed for reasons not clearly understood. On parts of the headland of Stackyard Field (Series C) at Woburn cereals grow very poorly. The land contains little organic matter and in 1958 the mineral nitrogen level in the soil determined the amount of growth made by barley; soil acidity also directly or indirectly affected growth, though much less. Some other factor or factors may be involved, and investigations will be continued in 1959. (Warren and Johnston.)

Changes caused by ploughing in straw

The changes in soil organic matter levels caused by ploughing in straw were measured in the Three-Course Rotation Experiment at Rothamsted. Dressings of straw ploughed-in at the rate of 53 cwt./acre every second year (and also compost made from the same amount of straw) increased the soil organic carbon level by 0·1 per cent and soil nitrogen by 0·005 per cent over 18 years. There was also a small increase in the value for " mineralizable " nitrogen on the plots that had had straw or compost. These changes in organic matter are inseparable from the changes in the potassium status of the soils caused by the straw. Values for K soluble in dilute acetic or hydrochloric acids were increased by 1 to 1·5 mg. K/100 g. of soil on plots that received compost or straw. (d'Arifat, Johnston and Warren.)

Forms of organic matter in soils

On land where arable crops have been grown continuously for long periods without adding organic manures, soil organic matter generally decomposes to release inorganic nitrogen at a slow but relatively constant rate. In contrast, recent additions of organic matter decompose rapidly and release nitrogen much more quickly. This behaviour complicates attempts to forecast the value of soil nitrogen reserves for crops. There is at present no chemical way of distinguishing between the " old " and " new " forms of soil organic matter, and an attempt is now being made to follow the changes when plant remains decay in soil. Ryegrass uniformly labelled with ^{14}C was grown from seed in a specially-constructed growth chamber and methods of following its decomposition in soil are being developed. (Jenkinson.)

Nitrogen in Soils

Fixed ammonium

Work on ammonium fixation in soil showed that much ammonia-N is taken up by soil organic matter when soils are treated with NH_3 gas. Treating such ammoniated soils with *N*–HF : *N*–HCl releases more ammonium-N than does treatment with *N*–KCl. The *N*–HF : *N*–HCl method of determining clay-fixed ammonium in soil previously described (*Rep. Rothamst. exp. Sta. for 1957*) should be modified for use with soils that have received nitrogen as

ammonia gas or ammonium hydroxide by including a pre-treatment with hot *N*–KOH to eliminate interference by ammonia-N fixed by soil organic matter. Other investigations made in collaboration with workers at Iowa State College and at the University of Illinois show that methods of determining clay-fixed ammonium in soil based on the use of cation exchange resins or of fine grinding are unlikely to be useful. (Bremner.)

The effect of low-temperature storage on inorganic nitrogen in soil

When freshly taken samples of moist soil are stored at ordinary temperatures, their contents of inorganic nitrogen change, and any laboratory measurements of ammonium and nitrate must be done immediately. The effects of storage at temperatures near to, and below, freezing point, were therefore studied. Inorganic-N contents of a series of soils were doubled during 28 days storage at 2°. Alternate freezing (−10°) and thawing (2°) during 32 days, such as is necessary during repeated sampling of frozen soil samples, also greatly increased inorganic nitrogen. Both these pre-treatments also affected the amounts of inorganic-N released when the soils were incubated at 25° for 21 days. Continuous storage at −10° for 32 days had no effect on the inorganic-N contents of the soils or on their behaviour when incubated. Freezing the moist soils was also a good way of conditioning them for sieving and sub-sampling. (Gasser.)

Changes in inorganic nitrogen levels in soil

In an experiment on wheat a part of each plot was uncropped and inorganic-N levels were followed both under the crop and in adjoining bare soil. Nitrate fertilizer applied in October was lost from the upper 6 inches of uncropped soil by mid-January, but where ammonium fertilizer was applied some was still retained in the top-soil. The amounts of inorganic-N in the surface soil of all the plots which had received their nitrogen in autumn (either as ammonium or as nitrate) were the same as the amounts in unfertilized plots from March onwards. Nitrogen fertilizers supplying 100 lb. N/acre and applied in mid-March were taken up rapidly by the wheat. By June, three-quarters of the N supplied by ammonium sulphate had been removed, and five-sixths of a dressing of calcium nitrate. On uncropped plots the nitrogen fertilizers applied in March persisted through most of the season, but by September all of the calcium nitrate had been lost from the surface soil and only one-sixth of the inorganic-N from ammonium sulphate dressings remained.

In a field experiment on uncropped land, increasing the amount of cultivation did not increase the amounts of inorganic-N in the surface soil.

A few plots of the Broadbalk Wheat Experiment were sampled at intervals through one season, and the amounts of nitrate in the surface soil were determined to provide information relevant to the work at other centres. On the section of Broadbalk fallowed all summer, the soil on the plot that receives farmyard manure each year contained 44 p.p.m. NO_3–N in September; on plots receiving no manuring or inorganic fertilizers only, the levels were 10–15

p.p.m. NO_3–N. Where wheat had been grown the levels were only 5 p.p.m. on the farmyard manure plot, and 1–2 p.p.m. NO_3–N on the other plots. The nitrate content of the fallowed section fell steadily during autumn; nitrate levels in the sections which had carried wheat rose for a time during October through cultivating and ploughing the stubble. By November the nitrate levels of plots in sections that had carried wheat were the same as those of corresponding fallowed plots. On plot 15, which received 83 lb./acre of N as ammonium sulphate in autumn, the whole of this dressing had been lost from the surface 6 inches by March. Nitrogen fertilizers applied to other plots in March temporarily increased inorganic-N levels, but all the added N (83 lb./acre) had gone from the surface soil by mid-June. (Gasser.)

Mineralizable-N in soils

Investigations designed to correlate the " mineralizable-N " (measured by incubating soils) with the responses of crops to N fertilizers in field and pot experiments have been continued. (Gasser and Close.) The mineralizable-N values of air-dried soils stored for 6 months exceed those obtained when the soils are incubated immediately after air-drying. This appears to be a general effect; as it may interfere with the application of mineralizable-N values in assessing soil nitrogen status, the effects of various methods and times of storage are being studied. (Gasser.)

Field Experiments on Nitrogen Fertilizers

Cereals

Although farmers are generally advised that they should apply all the nitrogen fertilizer needed by autumn-sown cereals as a top-dressing in spring, many apply part or all of it at sowing time; in addition, there is little experimental evidence on the best time of applying spring dressings of nitrogen for modern stiff-strawed varieties. Capelle wheat was sown in October 1957 in six experiments which tested seedbed dressings of ammonium sulphate (supplying 0·6 and 1·2 cwt. N/acre) against equivalent top-dressings applied either in mid-March or in mid-May. Also, divided dressings, applied either at two, or at all three of the dates of manuring, were compared with single dressings. At harvest three of the experiments were standing and the other three were severely lodged. At the first three centres March dressings produced the highest average increases in yield, and May dressings the lowest; autumn applications were intermediate. Divided dressings gave lower yields than single dressings applied in March. There were large increases in yield from the first dose of nitrogen at all three centres, and the extra yields given by the second increment were profitable at two of the three centres. At the other three centres lodging decreased average yields; March dressings gave the lowest, and May dressings the highest, mean increases. March dressings caused severe lodging, May dressings slight lodging and autumn dressings had an intermediate effect.

Work on combine-drilling fertilizers with barley seed was continued in 1957 and 1958 to examine the possible risks of applying

the whole of the nitrogen needed for a full crop through a combine-drill, and to see whether benefits from drilling as compared with broadcasting were maintained when heavier rates of manuring were used. In 1957 the barley was sown on badly prepared seedbeds, and a spell of dry weather followed. Under these conditions drilling a heavy dressing of ammonium sulphate (0·9 cwt. N/acre) delayed emergence by 7–10 days, 0·6 cwt. N/acre gave a slight check and 0·3 cwt. N/acre was not harmful. In 1957 drilling gave higher yields than broadcasting at the low and medium levels of manuring, but was inferior to broadcasting at the highest rate. There was no check to growth in the moister and better-prepared seedbeds used in 1958, and drilling ammonium sulphate gave more barley grain than broadcasting at each level of manuring. Drilling adequate quantities of nitrogen with the seed of spring cereals does not seem to be dangerous, and higher yields will usually be obtained from dressings applied in this way.

The amounts of potassium fertilizers usually recommended for barley are based on pre-war experiments with older varieties and much smaller dressings of nitrogen than are justified now that new stiff-strawed varieties are grown. Four barley experiments were laid down in 1958 on potassium-deficient soils to measure the effects of potassium dressings used with medium and high rates of nitrogen. Yields were decreased in two experiments by the high rate of nitrogen (0·8 cwt. N/acre), as the crops were severely lodged, and at these centres potassium fertilizer had little effect. In the other two experiments there were responses both to nitrogen and to potassium and 0·9 cwt. K_2O/acre gave higher yields than 0·45 cwt. K_2O/acre. (Widdowson and Penny.)

Forms of nitrogen for kale

One experiment on kale compared seedbed dressings of ammonium sulphate, calcium nitrate and urea supplying 1·0 and 2·0 cwt. N/acre. Seedbed dressings of calcium nitrate and urea both decreased plant establishment considerably, and urea more than calcium nitrate, but at harvest both these fertilizers gave higher yields than ammonium sulphate. The crop responded well to nitrogen fertilizers, and yields were increased five times by the heavy dressings; nitrogen applied partly to the seedbed and partly in mid-season gave slightly higher yields than dressings applied wholly to the seedbed. (Widdowson and Penny.)

Grass

Pure stands of four kinds of grass (perennial ryegrass (S.24), timothy (Scotia), cocksfoot (S.37) and meadow fescue (S.215)) were established in spring 1958 to measure the responses of the individual species to three levels of nitrogen. The grasses were cut at silage stage. Unmanured yields of the four species were similar; at the two cuttings taken in 1958 cocksfoot gave the largest responses.

Another experiment was laid down with newly sown S.22 Italian ryegrass to measure the response to several levels of nitrogen fertilizer in the presence and absence of potassium dressings. Three cuts produced a total yield of about 4 tons/acre of dry matter on heavily manured plots; 0·3, 0·6 and 0·9 cwt. N/acre were applied

before each cut, and there were good responses for each additional dose. There were no responses in 1958 to potassium fertilizer at any of the levels of nitrogen given.

Attempts to obtain a slowly acting nitrogen fertilizer for grass have been continued. A commercially produced batch of urea–formaldehyde (" Urea-form ") was applied as a single dressing and compared with single and with repeated dressings of " Nitro-Chalk " supplying the same amount of total nitrogen in an experiment on S.22 Italian ryegrass. At the first cutting " Urea-form " gave a yield similar to that given by only one-third as much nitrogen applied as " Nitro-Chalk ", and afterwards " Urea-form " had little effect on the yield. When " Urea-form " and " Nitro-Chalk " were both applied as a single dressing before sowing, " Nitro-Chalk " gave consistently higher yields at the first and also at later cuttings. It is clear that a material of the type tested in this experiment is not as useful for grass as inorganic fertilizers and it is very much more expensive per unit of N. (Widdowson, Penny, Williams and Cooke.)

Ammonium sulphate, calcium nitrate, ammonium nitrate and urea were compared in small-scale field experiments on permanent pasture and on newly sown Italian ryegrass; both swards were cut several times at silage stage, and all the fertilizers greatly increased the yield. The materials listed were applied at 0·5 and 1·0 cwt. N/acre and were compared both as solids in the ordinary way and as solutions containing 5 per cent N. Tests were also made of dilute ammonia solution containing 5 per cent N. This damaged permanent grass severely and did not increase the yields; ammonia solution applied to the seedbed before sowing ryegrass did not affect germination but gave lower yields than the other nitrogen fertilizers. All the fertilizers tested (except ammonia solution) gave very similar yields from permanent grass, whether applied as solids or as solutions. Later in the season tests were made of dressings delayed by 14 days as compared with those usually applied immediately after taking a cut. " Late " dressings gave smaller responses than " normal " dressings, but the grass contained more nitrogen. In the experiment with Italian ryegrass, calcium nitrate was significantly better at both levels of dressing than the other fertilizers. Except for ammonium nitrate, all the fertilizers gave significantly higher yields when applied as solids than when applied in solution. However, the difference is small, so fertilizers in solution can be used on grassland when it is convenient to do so without much loss. (Nowakowski and Cooke.)

Effects of nitrogen fertilizers on the inorganic nitrogen in grass

Produce from the experiments testing solid and liquid fertilizers was used to investigate the effects of nitrogen dressings on the amounts of water-soluble ammonium and nitrate in the grass. A sample was macerated with water, and the ammonium and nitrate contents of the aqueous extracts were determined by the method of Bremner and Shaw (*J. agric. Sci.* **46** (1955), 320–328). Measurements of nitrate on both fresh and dried samples of grass were satisfactory, but labile nitrogen compounds appeared to be decomposed by the magnesium oxide used in the ammonium determination;

this cause of interference is being investigated. Ammonium levels in the grass were increased by increasing rates of nitrogen manuring, but the form of nitrogen fertilizer and the method of application had little effect. The type of fertilizer and the time and method of application had very large effects on the amounts of NO_3–N in the grass (Table 2). Nitrate contents of the grass rose to very high levels when calcium nitrate was applied; ammonium sulphate gave much lower levels and the values in grass grown with ammonium

TABLE 2

The effects of nitrogen fertilizers on the nitrate-nitrogen in grass

(All fertilizers supplied 1·0 cwt. N/acre)

	Form	Time * of application	NO_3–N in parts per million in dry matter of grass	
			Permanent grassland	Newly sown ryegrass
Without N	—	—	61	29
Ammonium sulphate	Solid	Normal	481	474
	Solution		234	257
	Solid	Late	800	—
	Solution		336	—
Ammonium nitrate	Solid	Normal	1,492	1,409
	Solution		316	301
	Solid	Late	1,309	—
	Solution		848	—
Calcium nitrate	Solid	Normal	946	1,479
	Solution		221	564
	Solid	Late	2,134	—
	Solution		1,124	—

* "Normal" applications were given just before the grass had begun to grow, "late" dressings were 14 days after this date.

nitrate were intermediate. When dressings were applied late (i.e. 14 days after the normal dressings) nitrate levels were generally greater. In the experiments on both permanent grass and newly sown ryegrass the nitrate levels were higher when the fertilizers were applied as solids than when they were given in solution. (Nowakowski and Cooke.)

PHOSPHORUS IN SOILS

Phosphate in acid soils

Soils from the plots of the Park Grass and Broadbalk Experiments, which had received the same manuring on each field but differed in pH, were used to investigate the effect of changes in pH on labile phosphate values. In Broadbalk soils both the total labile pool, and the phosphate concentrations in 0·02*M*–KCl extracts, were lower on the more acid soils. In contrast, on Park Grass the more acid plots had larger pools of total labile soil phosphate and gave higher concentrations of phosphate when extracted with KCl solution. These differences may be related to the different contents of organic matter in the two soils. (Talibudeen.)

The equilibrium concentrations of iron, aluminium and orthophosphate ions were measured in suspensions of acid soils in 0·02*M*–KCl solution. The ionic products of the solubility of compounds of the type $(Fe^{3+}$ or $Al^{3+})(OH)_2 \cdot H_2PO_4$ were calculated for groups of English and Indian soils. For soils with pH values (in 0·02*M*–KCl solution) of 3·6–4·2 the ionic products were very similar to the published solubility product values of synthetic preparations of iron and aluminium phosphates having the compositions stated. The ionic products calculated in this way for the phosphates in English soils were about 200 times greater than the average values for the Indian soils. The relationships between the potentials of dihydrogen phosphate and the hydroxide of the trivalent cation suggest that, in soils having pH values above 5·2, adsorption complexes of orthophosphate ions and the metal hydroxides are formed. In more acid soils compounds of the composition postulated above may exist in admixture with the hydroxides of iron and aluminium. (Chakravarti and Talibudeen.)

The reactions between 5 per cent suspensions (in 0·02*M*–KCl solution) of several clay minerals with a dilute phosphate solution ($4 \times 10^{-5}M$) were studied to find how phosphate influences the rate at which the minerals break down and the compositions of the products formed. For all the pH values used (3, 4 and 5), phosphate treatments raised the aluminium concentrations in the mineral suspensions. This effect was obtained with St. Austell and Merck kaolinites, with Wyoming bentonite and glauconite. Phosphate lowered the iron concentrations of the suspensions in contact with the kaolinites, but increased the concentration when the three-layer minerals were used. It appears that treatment with phosphate solution may degrade all clay mineral surfaces. The process is slow with kaolinites, and at pH 3 it probably reaches a peak 3 months after treatment begins; at higher pH values there is less total breakdown, but it is at a maximum only a month after applying the phosphate. With the three-layer minerals, breakdown was maximal after a month, at all pH values tested. A mild treatment with phosphate for 1 month dissolves aluminium and iron from three-layer minerals but with the two-layer minerals only aluminium is removed and the reaction is slower. With such degradation by phosphate, free silica must accumulate in the system. (Chakravarti and Talibudeen.)

Phosphate in calcareous soils

An investigation of the effects of organic anions and of temperature on the total labile phosphate (measured by isotopic exchange) has now been completed. In neutral and calcareous soils the labile soil phosphate is decreased by the presence of $10^{-3}M$ concentrations of citrate and diethyl-barbiturate ions; only that fraction of the labile soil phosphate which exchanges *slowly* is affected, and the effect is more definite with the diethyl-barbiturate ion. Citrate ions always increase the amount of labile phosphate in solution, and do so greatly at concentrations above $10^{-3}M$. Both ions speed up the process of isotopic exchange, but citrate is more effective than diethyl-barbiturate.

A group of calcareous soils containing varying amounts of total

phosphorus were used to investigate the effects of different temperatures on measurements of isotopically exchangeable phosphate made in a suspension of soil in 0·02*M*–KCl solution. All the quantities measured (rate of solution of phosphate, equilibrium concentrations, labile phosphate and its components, and also rates of isotopic exchange) changed regularly for all soils as the temperature was increased from 25° to 35°. When using soils with high phosphorus contents these changes continued regularly up to 45°; however, in soils containing less phosphorus there were abnormal increases in labile phosphate, equilibrium concentration and rate of exchange at 45°, suggesting that a new and more labile phosphate phase was formed at this temperature. The new phase appears to be associated with the slowly exchanging component, as its rate of exchange increases ten times between 35° and 45°, which is double the rate of change in soils of high phosphorus status. This work is being continued to see whether the apparent alteration in the calcium phosphates is due to hydrolysis at the higher temperature or to the presence of KCl.

Other experiments on neutral soils have tested the effect on labile phosphate of varying both the cations present in the exchange complex and also the extracting solution. The amount of labile phosphate was usually affected only slightly by varying the cation, but sodium soils generally gave higher values. In two anomalous soils the labile phosphate in a sodium system was much higher than in a calcium system; this appeared to be due to the solution of organic phosphate. (Arambarri and Talibudeen.)

The isotopic exchange of calcium ions in aqueous solution with precipitated calcium carbonate was studied as a prelimary to investigating the absorption of orthophosphate ions by calcium carbonate. The kinetic features of the reaction are:

(i) a very fast exchange which is mostly complete after ½–1 hour;
(ii) a slow reaction which continues indefinitely.

The former is probably true surface exchange, whereas the latter may be due to exchange with layers deeper than the surface layer or may be the result of recrystallization. By assuming that the most frequently occurring crystal face in the calcium carbonate is the rhombohedral cleavage face (microscopic examination confirms this), it was calculated that there are two calcium atoms per 40·2 Å.^{2}. The specific surface calculated by using this figure is given below:

Ca concentration in solution, $M \times 10^{-4}$	Specific surface, M^2/g.
1·6	0·155
2·1	0·160
4·0	0·139

The specific surface calculated from the size analysis (determined by a sedimentation velocity method) was 0·076 m.^{2}/g. The difference between the " geometric " surface and the exchange surface may be partly due to the shape of the particles (because the geometric surface is based on that of equivalent spheres) but as this shape factor

is unlikely to be as large as 2, additional internal surfaces must be involved. The exchange surface is, of course, the most important quantity in studies of the adsorption of phosphate on calcium carbonate. (Newman.)

"Available" soil phosphate

Most methods of analysing soils to determine phosphate are empirical, and may fail if the extractant used dissolves phosphate which cannot be used by the crop grown. ^{32}P-labelled superphosphate was added to soils, which were then extracted with several conventional reagents to see whether they dissolved phosphate unable to exchange with labelled superphosphate. Total exchangeable phosphate ("A") values were measured for these soils in a greenhouse pot experiment on ryegrass. The acid reagents used (1 per cent citric acid, 0·5*M*-acetic acid, 0·002*N*-sulphuric acid and 0·3*N*-hydrocholoric acid) all gave much higher mean values for "available" P (27–32 mg. P/100 g. of soil) than the "A" values measured in the pot experiment (average value 19 mg. P/100 g. of soil). An acetic acid–sodium acetate buffer solution and a 0·5*M*-sodium bicarbonate solution at pH 8·5 gave mean values (19 and 17 mg. P/100 g. of soil respectively) which were closer to the "A" values determined in the pot experiment. Acid reagents dissolve more soil phosphate than is contained in the pool of latent phosphate crops can use. Two acid sandy soils derived from the Trias gave an extreme example of this effect; when they were extracted with citric acid nearly all of the inorganic phosphate was isotopically exchangeable, but in the greenhouse experiment little more than half was exchangeable. (Mattingly, Pinkerton and Close.)

It is very difficult to analyse satisfactorily by conventional methods for "available" phosphate when soils contain much free calcium carbonate. Several soils of the Sherborne Series derived from Oolitic Limestone were examined in joint work with Mr. R. D. Russell of the National Agricultural Advisory Service. The amounts of phosphate extracted from the soils by 0·5*M*-$NaHCO_3$ at pH 8·5 and the isotopically exchangeable phosphate were both closely related to the phosphate status of the soils measured in pot experiments. The phosphate concentrations of the soils measured in 0·01*M*-$CaCl_2$ solution were less useful. It appeared that responses to phosphate might be expected in soils containing less than 0·9 mg. P (soluble in bicarbonate solution) or having "A" values of less than 7 mg. P/100 g. of soil. (Mattingly and Close.)

Work on the Exhaustion Land and Four-Course Rotation experiments at Rothamsted showed that, even for soils with small amounts of calcium carbonate, acid extractants gave high values which did not agree with the performance of crops. Extracting these soils with sodium bicarbonate solution was satisfactory, and this method was also most suitable for examining the soils from the Agdell Experiment. The multiple cropping planned for Agdell in 1959, together with the proposed changes in the Barnfield Experiment, will provide excellent material for further tests on this and other methods. (Warren and Johnston.)

Potassium in Soils

Removal of potassium by crops

When arable root and forage crops or grass are removed from land much potassium is carried away. When cropping of this kind is continued for long, soil potassium is depleted and must be replenished by manuring if crop yields are to be maintained. In the

Table 3

Amounts of potassium removed by the treatment crops in the Rothamsted ley–arable experiments

(Cwt. of K/acre/year)

Field (history)	Mean values for 1954 and 1955		Mean values for 1956 and 1957	
	Highfield (old grass)	Fosters Field (old arable)	Highfield (old grass)	Fosters Field (old arable)
Treatment cropping with leys				
Cut grass:				
Year 1	1·7	1·3	2·0	1·4
Year 2	1·1	1·3	2·2	2·0
Year 3	0·6	1·0	1·8	1·8
Lucerne:				
Year 1	0·7	0·7	0·7	0·5
Year 2	1·5	1·7	1·7	1·8
Year 3	1·1	1·2	1·3	1·8
Grazed ley:				
Year 1	1·1	1·0	0·8	0·6
Year 2	1·4	1·1	1·0	0·8
Year 3	1·3	1·0	0·6	0·6
Permanent cropping				
Reseeded grass grazed ...	1·0	1·0	0·8	0·6
Reseeded grass cut for hay and then grazed:				
Hay period	1·2	1·2	1·2	0·7
Grazed period	0·4	0·4	0·5	0·6
Permanent grass grazed ...	0·9	—	0·8	—
Permanent grass cut for hay and then grazed:				
Hay period	1·0	—	1·3	—
Grazed period	0·4	—	0·6	—
Arable rotation treatment				
Seeds hay	—	—	0·7	0·7
Potatoes:				
Without farmyard manure	—	—	0·7	0·8
With farmyard manure	—	—	1·2	1·1
Oats (grain + straw) ...	—	—	0·4	0·3

ley–arable experiments at Rothamsted, K-deficiency occurred in test crops following 3 years of either cut grass or lucerne. The crops grown in several recent years were analysed to provide a basis for applying the extra potassium needed to maintain both the K-status of the soils and the crop yields (Table 3). Supplementary dressings of potassium fertilizers, equivalent to the amounts of potassium removed by the leys, have now been applied since

1956. The two pairs of years, 1954 with 1955 and 1956 with 1957, therefore compare K uptakes by the ley crops for two levels of K manuring. On average of the 2 years before supplementary potassium fertilizer was applied, the uptake of K by the cut grass grown on Highfield (the old grassland soil) decreased markedly with the age of the ley; there was only a small decrease on the old arable site, where the soil contained initially more readily soluble K than the old grassland soil. Applying extra K fertilizer in 1956 and 1957 prevented this fall in K uptake on the cut-grass plots. In the first period first-year lucerne removed less K than was taken up by first-year cut grass; uptake by lucerne was most in the second year and decreased in the third; the extra potassium given in the second period maintained the level of K uptake by third-year lucerne on the old arable soil but not on the old grassland soil. In contrast, where the leys were grazed the uptakes of potassium in the first period were very similar for all stages of the ley and for both soils. In the second period the uptakes by grazed ley decreased to about two-thirds of the previous values for both soils and all 3 years; this was due to lower yields and not to a fall in the potassium contents of the grass, which were maintained at about 3·5–4·0 per cent K (of dry matter) for the whole of the 4 years. Both cut grass and lucerne leys removed more potassium than the annual crops grown in the arable rotation.

The effects of the potassium deficiency which developed in the early years, and of the supplementary dressings which were given to correct the deficiency, have been measured on the test crops of potatoes (Table 4). In 1955, 1956 and 1957 the potatoes were grown

TABLE 4

The responses of potatoes to dressings of potassium fertilizer in the ley–arable experiments at Rothamsted

	Preceding ley crop		
	Lucerne	Cut grass	Grazed ley
	Response to K fertilizer (tons of potatoes/acre)		
Highfield			
1955	1·34	1·67	1·07
1956	2·22	2·31	0·78
1957	1·84	1·78	0·60
1958 *	−0·30	−0·56	0·77
Fosters Field			
1955	0·65	0·95	0·34
1956	1·16	0·48	0·70
1957	1·26	0·29	0·48
1958 *	0·03	−0·43	0·77

* Supplementary K had been given to the plots which had grown lucerne and cut grass.

following crops which had not received *extra* K; the cut grass and lucerne leys which preceded the 1958 potato crop had received extra K fertilizer to compensate for the greater uptake, but the grazed ley plots did not receive any extra K in any year. For the years 1955–57 the mean response by potatoes to potassium fertilizers in Highfield was 1·8 tons/acre where they followed lucerne and

1·9 tons/acre where they followed cut grass, no supplementary K was given to these leys; following grazed ley the mean response was 0·8 ton/acre. In 1958 on plots where the lucerne and cut grass had received supplementary potassium the test dressings of potassium had no significant effects on yield. After grazed ley the potatoes gave the same response (0·8 ton/acre) in 1958 as was obtained on average of the earlier years. Many of the effects of potassium fertilizer on potatoes following grazed leys were not statistically significant, nevertheless the results are very consistent, and when all years are taken together they indicate a fall in potassium status on these plots. On Fosters Field the trends were similar to those measured on Highfield, although the actual effects were smaller, presumably because the old arable land contained more potassium at the beginning of the experiment than the old grass field. The supplementary dressings of potassium now given to the lucerne and cut-grass treatments appear to be stopping the drain on soil potassium. From 1958 onwards the potassium dressing given to the grazed ley has also been increased from a total of 1·2 cwt. K_2O/acre (for the 3 years) to 1·8 cwt.

The crops from the Woburn ley–arable experiment were similarly examined. Where no farmyard manure is given in the continuous arable rotation, and in the arable rotation which includes a hay crop, the amounts of K removed by the crops exceed the amounts added over the 5-year period of the rotation. Where farmyard manure is applied all rotations receive more K than is removed. (Warren and Johnston.)

Potassium fixation in Rothamsted and Woburn soils

Soil analyses showed that, when a fresh dressing of potassium fertilizer is added to the soil of the Exhaustion Land experiment, a large proportion is quickly converted to a non-exchangeable form. In laboratory experiments on slightly calcareous Rothamsted soil at least 80 per cent of the K present in a solution added to the soil was held in a non-exchangeable form; over a wide range of additions of potassium, from well below to well above the usual rates of applying K fertilizers, the amount fixed was proportional to the amount added. Acid Rothamsted soil, and slightly acid Woburn soil, both fixed only about half of the added potassium. The soils of the classical experiments will be analysed to see how much of the K added each year over long periods has been fixed. (Warren and Johnston.)

Availability of soil potassium

In many soils, particularly those low in exchangeable potassium, some fraction of the reserves of non-exchangeable potassium may be of value in crop nutrition. Pot experiments cropped continuously with perennial ryegrass are being used (with Close) to measure the rate of release of non-exchangeable potassium from a number of soils which are taken as standards in associated laboratory work on the value of cation-exchange resins for extracting potassium. The sodium form of "Amberlite IR-120" takes up approximately the amount of potassium that can be exchanged by leaching with neutral N ammonium acetate; the calcium resin takes up less and the hydrogen resin extracts considerably more potassium than is

ammonium-exchangeable. The amount of non-exchangeable K extracted by H-resin in 14 days and the uptake of non-exchangeable K from the soil by 3 or 4 cuts of ryegrass grown in pot experiments agreed well. Some soils must be partially dispersed with sodium hexametaphosphate before adding the H-resin to obtain a sufficiently rapid reaction. The technique may be applied successfully to calcareous soils provided that wide ratios of resin to soil are used, together with a longer time of extraction; non-exchangeable potassium is released after the calcium carbonate has been dissolved by the resin, and from some calcareous soils quite large quantities may be extracted. In well-weathered soils most of the non-exchangeable K extracted by H-resin comes from the clay fraction: a soil overlying Malmstone was an exception, the 2–10-μ fraction releasing one-third as much K as the clay fraction. Extraction with H-resin for 14 days recovered at least 90 per cent of the potassium recently " fixed " by wet soils, but the results with soils that had fixed potassium on drying varied much more. H-resin extracted potassium which was not ammonium-exchangeable from certain minerals; dioctahedral micas released little of their non-exchangeable K to H-resin, but considerable quantities were released by trioctahedral micas. (Arnold.)

The amounts of exchangeable soil potassium and the amounts soluble in dilute HCl correlate satisfactorily with the K taken up by arable crops on the Exhaustion Land and on Agdell. Some of the potassium supplied by fertilizer dressings is held in a form not readily exchangeable; attempts were made to determine the amounts held in this way and their relation to exchangeable K. Repeated extractions with hot HNO_3 dissolved about ten times as much fixed fertilizer potassium as was exchangeable. For the grass crop grown on the Agdell experiment in 1958, the relationship between K uptake and exchangeable K levels in the soil was not satisfactory, and more work is needed to define the behaviour of different crops towards soil potassium. (Warren and Johnston.)

Potassium deficiency in spruce seedlings

Sitka spruce seedlings showing severe signs of potassium deficiency were tested for putrescine, but none was found. The purple colour of the leaves was due to an anthocyanin. (Jenkinson.)

The Value of Phosphorus and Potassium Reserves in Soils of the Long-term Experiments at Rothamsted

Work has continued on the residues of P and K fertilizers which have accumulated in the soils of the Exhaustion Land and Agdell experiments from manuring.

The Exhaustion Land experiment

R. G. Warren showed (*Proc. Fertil. Soc.* 1956, no. 37) that the residues from P and K fertilizers applied before 1901 were useful to barley grown in the period 1949–53. In 1957 and 1958 this work was taken further by subdividing the old plots and superimposing tests of new dressings of P and K fertilizers on six crops (barley, spring wheat, potatoes, sugar beet, swedes and kale) which were

grown side by side. All plots received a basal dressing of N fertilizer, basal P fertilizers were given when K was being tested and basal K was given where test dressings of P were applied. The increases in yields given by new additions of P and K fertilizers are stated in Table 5 for the six crops grown in 1957 and 1958.

TABLE 5

The increases in yields given by fresh additions of P and K fertilizers in the Exhaustion Land experiment

	Increase from new dressing of 1·0 cwt. P_2O_5/acre				Increase from new dressing of potassium fertilizer *			
Manuring in 1856–1901 period	No phosphate		Phosphate		No potassium		Potassium	
Year	1957	1958	1957	1958	1957	1958	1957	1958
	Increase in yield (per acre) of new test crops							
Barley (cwt. of grain) ...	6	15	0	5	1	0	0	1
Wheat (cwt. of grain) ...	2·5	10	0	2	0	1	0	0·5
Potatoes (tons of tubers)	8	8	4	5·5	6·5	5	4	3
Sugar beet (tons of roots)	3·5	4·5	0	2	0	3·5	0	0
Swedes (tons)	5	13	0·5	3	0	2	0	0
Kale (tons)	6	6	2·5	2	1	0	2·5	0

* 1·2 cwt. K_2O/acre for potatoes, sugar beet and kale; 0·6 cwt. K_2O/acre for cereals and swedes.

The weather in the first half of the two seasons differed; in 1957 there was a drought until July, and in 1958 it was wet. After early July in each year rainfall was above average. This difference in spring and early summer rainfall in the two years was reflected in the responses of barley and wheat to fresh dressings of phosphate. For both crops the increases in yield were much greater in the wetter season. In 1957 residues of phosphate in the soil resulting from manuring between 1856 and 1901 sufficed to grow full crops, and adding superphosphate did not increase yields. In the wet year (1958) barley grown with phosphate residues alone gave 5 cwt./acre of grain below the maximum yield obtained by applying superphosphate; similarly, wheat grown with P residues alone yielded 2 cwt./acre less than the maximum obtained by applying superphosphate. The greater responses to new dressings of phosphate measured in 1958 occurred because the cereals without fresh phosphate gave smaller crops than in 1957 and not because the treated crops yielded more. As there is no reason to consider that the chemical "availability" of the phosphate residues in the soil was less in the wetter than in the drier year, it is likely that the accessibility of the phosphorus differed, perhaps because root growth differed in the 2 years.

Potatoes, sugar beet and kale responded similarly in both years to new dressings of phosphate where these crops were grown on soil which received no phosphate from 1856 to 1901 (and none since). The mean yield of sugar beet in 1958 was 50 per cent greater than in 1957, kale gave a 25 per cent higher yield in the later year and potatoes gave similar mean yields in the two years. On the same soil the response of swedes to new dressings of phosphate was much greater in 1958 (13 tons/acre) than in 1957 (5 tons/acre); the mean yield of swedes in 1958 was double that obtained in 1957. The phosphate residues from the old manuring were sufficient for full crops of barley, wheat, sugar beet and swedes in 1957 but not in

1958. In 1958 the phosphate residues were equivalent to about one-half to four-fifths of the value of the new phosphate fertilizer dressing for these crops. For potatoes and kale the phosphate residues were inadequate in both years: each year the extra yield of potatoes from the residues was only half as great as the increase given by a new dressing of 1 cwt./acre of P_2O_5. For kale the corresponding extra yields in the 2 years were about two-thirds as great as the responses to new dressings.

On soil that received no potassium manuring between 1856 and 1901 (and none since) fresh dressings of potassium fertilizer greatly increased yields of potatoes in both years. In 1957 there was little or no increase in yield of the other crops grown due to fresh dressings of potassium; in 1958, however, new dressings of potassium also increased the yields of sugar beet and swedes; as in 1957, cereals and kale did not respond. On other plots that had received potassium between 1856 and 1901 barley, wheat, sugar beet and swedes obtained sufficient potassium in both years from the residues left in the soil. Potatoes, however, responded well to fresh dressings of potassium in both years, kale gave a moderate increase in yield in 1957 only. (Warren and Johnston.)

The Agdell experiment

R. G. Warren (*Rep. Rothamst. exp. Sta. for 1957*, p. 252) has described the soils of the Agdell experiment and summarized the immediate and residual effects of fertilizer dressings on crop yields up to 1957. Hitherto, information obtained on residual effects has been for the combined effects of the residues from P and K manuring; plans are now being made to separate the effects of the two nutrients for several crops in 1959. This work usefully extends that on the Exhaustion Land, because the levels of the residues from P and K manuring are higher on Agdell. In 1958 Italian ryegrass was sown on half of each of the Agdell plots. The grass was cut twice at silage stage and analysed (with the help of Widdowson and Williams). The amounts of P and K (in lb./acre) extracted in 1958 by the two cuts of grass were:

	P	K
From unmanured soil	5·5	105
From soil containing residues from PK manuring ...	19	205
Gain from residues	13·5	100

The *extra* amounts of P and K taken up by the grass from the plots containing PK residues were only a little greater than those taken up by the potatoes grown in 1957 (10 lb. of P and 95 lb. of K/acre). There was, however, a large difference in the *total* amounts of K removed by the two crops, which is not shown by the values for " gains from residues ". In 1958 grass grown on the " unmanured " plot extracted four times as much potassium as did the potatoes in 1957, but less than twice as much phosphorus. The greater extracting power of grass than of potatoes no doubt partly comes from a longer season of growth and from more complete " searching " of the soil by the grass roots. (Warren and Johnston.)

Cation-exchange Capacity of Plant Roots

There has recently been considerable interest in the cation-exchange capacity of plant roots. The literature suggests that the values recorded are relative rather than absolute, and the reactions at or on a root surface include diffusion and possibly chelation as well as simple exchange. The concept of an exchange capacity of roots may have some use in work on the uptake of cations. In preliminary investigations the exchange capacities of well-washed roots were determined in three ways: (1) The roots were allowed to take up barium, which was then displaced by acid. (2) Titration curves were obtained after the root material had reached equilibrium in a dilute HCl–KCl solution. (3) In a few experiments roots pre-treated with neutral dilute $CaCl_2$ solution were allowed to exchange with another $CaCl_2$ solution containing ^{45}Ca; rates of isotopic exchange were then determined by a scintillator counting technique. Values obtained by barium exchange were reproducible, and this method appeared to be more satisfactory than that involving titration of the roots. Rather few values were determined by using ^{45}Ca, but they agreed with those given by the barium exchange method. All three methods were used to obtain information on the roots of several crops.

Values given below for cation exchange capacities are in milli-equivalents/100 g. of dry root. The lowest value (1·7) was found with 2-year-old lucerne roots and the highest (75) with peas grown in pots. Perennial and Italian ryegrass, cocksfoot and timothy all gave similar values (20–28 m.e.q.) although some of the roots used were grown in pots and others were taken from the field. The range of values for wheat and barley from pots or the field was 12–16 m.e.q. In general, the values determined resemble those quoted by other workers except for red clover. Published information states that clover has an exchange capacity of 40–50 m.e.q., but four samples used in this work gave values of 13–16 m.e.q. For some of the crops measurements were made at several stages of growth. There was little change in cation-exchange capacity of wheat roots during spring and summer; with kale and clover the values decreased as the season advanced. The effects of fertilizers on cation exchange capacities of roots were not consistent. In field experiments the values for wheat and for permanent grass were not affected by nitrogen fertilization, but with newly sown Italian ryegrass in the field, and with barley grown in sand culture, nitrogen fertilizer increased the exchange capacities of the roots. Increases were also caused by phosphate manuring of perennial ryegrass grown on calcareous soil in a pot experiment. Exchange capacities of barley roots were influenced by variety and by applications of potassium fertilizer. This work will be continued to see whether cation-exchange capacities of roots can be related more closely to the uptake of nutrients by plants grown under controlled conditions. (Heintze.)

Analytical Work

Determination of nitrogen in soils

The value of the Kjeldahl method for determining nitrogen in soils was studied by testing the effects of changes in the temperature of digestion, in the catalyst, and in the period of heating. For a range of soils containing from 0·03 to 2·7 per cent of N, the most important factor in Kjeldahl analysis was the temperature of digestion with sulphuric acid, which was controlled by the amount of potassium sulphate added. Under the conditions normally used for Kjeldahl digestion of soil there is little risk of loss of nitrogen due to consumption of sulphuric acid with consequent rise in the temperature of the digest. Selenium was the most effective catalyst for Kjeldahl digestion of soil. The method recommended by the Association of Official Agricultural Chemists gave much lower values than the other methods tested, but satisfactory results were obtained with this method when the period of digestion was increased to 5 hours. The values obtained by Kjeldahl analysis were not affected if the soils were pretreated with HF and H_2SO_4 (to release organic nitrogen and ammonium fixed by clay minerals) or with HI (to include compounds with N–N and N–O linkages). Kjeldahl methods modified to include refractory nitrogen compounds such as nicotinic acid and tryptophan gave the same results as the normal procedures, and it seems that soils contain little of such materials. The Kjeldahl methods normally used for soil analysis are satisfactory if digestion is continued for several hours. The period of digestion required can be decreased by adding more potassium sulphate. The results with micro-Kjeldahl procedures using 0·3–1·0 g. of soil ground to pass a 100-mesh sieve were highly reproducible and identical with those obtained by macro-methods using 5–10 g. samples of soil. (Bremner.)

Calcium in crops

When the EEL flame photometer is used to determine calcium in crops, anions which are present at similar concentrations affect the results. This interference is much decreased by " blanketing ", but with phosphate ions there is serious loss of sensitivity. J. Yofe and R. Finkelstein (*Anal. chim. Acta*, **19**, 1958, 166) showed that the lowering of the calcium emission caused by phosphate can be restored by adding lanthanum chloride when using a Beckmann D.U. spectrophotometer. This method can be applied to the EEL flame photometer, and the best results are obtained with a higher air pressure (15 lb./sq. in.) than is recommended for K (10 lb./sq. in.). Ten times as much lanthanum as phosphate (on an equivalent basis) is necessary and thirty times as much is tolerated. (Johnston.)

Potassium in soils

All naturally occurring potassium minerals contain the radioactive isotope ^{40}K, which provides about 0·01 per cent of all the K present. Soils have a little natural radio-activity from the isotope, and measurements were made to see whether it can be used to determine the total amount of soil K present, so that the customary tedious analytical methods, which involve destroying the silicate

minerals, can be avoided. Soil samples ground to pass a 40-mesh sieve were packed in a M12 liquid Geiger–Müller counter, and packing density and counts per minute were measured. The method was calibrated against determinations made with mixtures of pure minerals and sand. The potassium contents of about twenty soils from Southern and Eastern England measured by counting were slightly higher than the values obtained by chemical analyses, perhaps because the soils contain small quantities of uranium and thorium. Discrepancies between results obtained by counting and by analysis were greater with soils formed from igneous rocks in Scotland and Wales. As the method is rapid and may prove very useful, the interference by other radioactive elements is being studied. (Rodriguez, Mattingly and Talibudeen.)

PEDOLOGY DEPARTMENT

A. Muir

Mineralogy

Iddingsite

The study of this mineral has been completed (3.3). The only major change in the interpretation of the X-ray photographs as given in the report for 1956 is that reflexions then supposed to arise from a super-lattice have now been shown to be more probably due to goethite in two subsidiary orientations in addition to the main orientation parallel to the original olivine. (Brown and Stephen.)

Jarosite

The claim to the first record of this mineral in soils has proved an error, because it had earlier been reported by E. M. Chenery (*The Soils of Central Trinidad*, 1952). However, the study of the mineral has continued because the data in the literature on cell constants of the end members (the K and Na varieties) conflict. An examination of analysed samples of jarosite (K-member) and natrojarosite kindly supplied by Dr. A. W. G. Kingsbury, Oxford University Museum, has indicated a relationship between the cell constants of the mineral and its relative potassium and sodium contents. Assuming this to be linear for the *c* crystallographic dimensions, the jarosite-type mineral from Bow Brickhill should contain the alkalies in the proportions 72 per cent K and 28 per cent Na. Chemical analysis gives 74 per cent K and 26 per cent Na, which suggests that the alkali cation content of the members of the series jarosite–natrojarosite could be quickly and accurately determined from measurement of the *c* dimension by X-ray diffraction. (Brown.)

Loess-like deposits in southern England

Mineralogical and other studies at Rothamsted and elsewhere have shown the probability that many soils are developed, at least in part, in loess-like material. In the Chilterns the rich assemblage of heavy minerals found in the silty surface horizons of soils on plateau drift contains species which are rare or absent from the substrata. The origin of the added minerals cannot yet be deduced, but glacial and glacio-fluvial drift are obviously possible sources. A mineralogical comparison of Chalky Boulder Clays from Hertfordshire and Buckinghamshire, on either side of the Chiltern Hills, showed a general predominance of garnet, epidote and hornblende over tourmaline and staurolite, which is similar to assemblages previously reported for glacial drifts of similar age in East Anglia. Such deposits or their outwash could have supplied all the minerals characteristic of the Chiltern silty deposits, except possibly for a chlorite which is never important in the glacial drifts but is prominent in the silts. The type of chlorite is, however, identical in both

materials, and it may be locally more abundant in the boulder clays. The department is also co-operating with the Soil Survey in the examination of a similar problem in Somerset (*Soil Survey of Great Britain, Reports 9 and 10*). (Stephen.)

Micropedology

It is becoming more and more apparent that a straightforward soil profile description is not a sound basis for soil classification. The techniques of thin-section investigation have brought out features that had hitherto escaped notice or were only vaguely suspected, but are a distinct aid to classification.

The study of thin sections of the Chiltern soils referred to previously (*Rep. Rothamst. exp. Sta. for 1956*) has been completed. With certain soils developed in loess-like material, there is good evidence for clay migration down the profile, which in part accounts for the considerable change in texture in the subsoil. An examination of several soils developed in silt material overlying Carboniferous Limestone on the Mendips showed that they, too, possess micromorphological features indicating clay migration and deposition with the formation of textural-B horizons. Such features suggest that the soils are related to grey-brown podzolic soils (Frei and Cline (1949), *Soil Sci.* **68**, 333) or parabraunerde (Kubiena (1956), *Eiszeitalter und Gegenwart*, **7**, 102). A preliminary study of some soils of the group "red and brown calcareous soils" overlying Oolitic Limestone on the Cotswolds indicated the possibility of their assignment to such groups as brown rendzinas, ferritic braunerde and terra fusca (Kubiena (1953), *Soils of Europe*). Dr. R. R. Storrier showed that the soils on the Banbury ironstone were of the ferritic braunerde type, whereas others in that area could be considered as braunerde and rendzinas.

Thin sections of some "red soils" from various parts of Africa were prepared for comparison. In particular, it was hoped that a study of the red earths from Tanganyika might help to explain why they set so very hard when dry and are so abrasive when worked (cf. *Rep. Rothamst. exp. Sta. for 1950*, p. 46). These soils contain much coarse sand and clay and little fine sand and silt. Thin sections of clods from the top foot show the coarse sand to be dominantly angular quartz. There is evidence of clay movement and its accumulation on the walls of pore spaces. It appears that intense rainfall in the wet season promotes clay shift that is confined mainly to the upper layers of the soil and results in most of the pores in the subsurface soil becoming clogged with close-packed clay. The clay is mainly non-swelling kaolin, so that a massive structure is produced, and it is suggested that this structure of dense, massive peds studded with firmly held angular quartz grains would be highly abrasive. (Stephen and Osmond.)

Clay Mineralogy

The samples of soils examined during the year for their clay mineral content have come from various countries. British samples included soils and parent materials from Somerset, parent materials

from Shropshire, and clays and limestones from various parts of England.

The parent materials from Somerset range from the Devonian to the Lower Jurassic, and generally showed moderate or dominant mica. The presence of an appreciable amount of sepiolite in a Triassic marl sample was noteworthy. Parent materials from Shropshire included samples from Upper Coal Measures, Downtonian and Dittonian. A remarkable variation in the clay composition of the Downtonian was indicated by the presence of a considerable amount of montmorillonite in all the Ledbury Marls examined and its complete absence in the other Downtonian samples which consist in the main of mica and kaolin. (Du Feu.)

It has been suggested that the mineral palygorskite, which has been reported as widespread in Middle East soils (*Rep. Rothamst. exp. Sta. for 1957*, p. 67) might be of pedogenetic origin. By courtesy of Mr. R. H. S. Robertson it has now been possible to examine some Iranian rock samples and a clay undoubtedly derived from igneous rock material. Some of the sedimentary rocks showed the presence of palygorskite, but there was no sign of it in clay from igneous rocks. This suggests that the palygorskite in the soils is derived from their parent rocks and is not formed by contemporary weathering or pedogenetic processes.

The Ukiriguru soil catena in Tanganyika is being studied. This sequence of soils derived from granite ranges from shallow red brown soils just below a tor, through rather sandy soils, some of which develop an extremely hard pan on drying, down to the heavy black mbuga clays. The soils on the upper slopes contain largely kaolin and mica; in the sandy soils montmorillonite comes in at depth, and together with slight sodium saturation undoubtedly contributes to the pan formation; the montmorillonite increases in quantity as the mbuga soil is approached, and in this is by far the dominant clay. (Du Feu and Muir.)

Effect of sodium hydroxide attack on montmorillonites

Previous work on the Black Jack Mine beidellite specimen suggested that the small-particle-size material seen in electron micrographs and the 350° C. endothermic d.t.a. peak might be from an aluminous impurity. To test this hypothesis samples of the beidellite and three pure montmorillonites, Wyoming, Redhill and Unter-Rupsroth, were extracted for 4 hours at 100° C. in 0·5*N*-sodium hydroxide. The beidellite, of which about 20 per cent dissolved, was the only one appreciably attacked. The others showed some selective extraction of silica, but the amounts were too small to make a significant difference in the total analysis figures. Calculation of the half-unit cell contents from the analysis of the extracted beidellite showed a slight shift towards an ideally dioctahedral mineral and reduction in inter-layer charge. The change was small, however, and the dissolved material could not be called an aluminous impurity. It was difficult to say whether it was the small-particle-size material that had been dissolved. Where the sample dispersed easily this appeared to be so, but where the material did not disperse, electron micrographs showed considerable attack on large flakes. Extraction of the beidellite showed no change in the 350° C.

endothermic d.t.a. peak, and further work showed that such a peak is a common feature in minerals of this type. There seems no reason to doubt that the beidellite is a pure end-member of the montmorillonite–beidellite series. The work has also confirmed the use of sodium hydroxide extraction for the removal of fine-grained silica and to some extent alumina impurities for the calculation of unit cell contents, but it is very doubtful whether it can be regarded as a useful-pre-treatment for samples. (Weir.)

Electron microscopy

The technique of spraying on the grid has been used successfully with some montmorillonite minerals. It can be used as an exploratory method complementary to optical microscopy, and with a range of magnification of 200–20,000 the whole sample can be surveyed initially and then areas selected and examined with increased magnification. The Unter-Rupsroth montmorillonite proves to have an undisturbed structure similar to that of the beidellite, but the electron micrographs are less spectacular, because the flakes are equi-dimensional rather than lath-shaped and do not dry into such clear-cut fans.

Considerable work has been done on the electron microscopy of unshadowed montmorillonite mounts. At first a magnification of 5,000 was thought best for these very thin materials and lack of contrast was considered to prevent successful results at 20,000 or 40,000, but this has proved mistaken. The use of very thin carbon films has improved contrast, but the physical state of the sample is the most important factor. Washing and high-speed centrifuging removes what appears to be a decomposition product of the clay minerals, which otherwise blankets the entire mount and drastically reduces contrast. Further work will be needed to define the chemical composition of this material, the conditions under which it is produced and its volume relations to the original sample. The presence of such material has probably been overlooked previously in shadowed mounts because sufficient relief remained for shadows to be cast, and the contrast between metal and shadow was the dominant feature. In addition, the tendency of flakes and flake-shadows to disappear into the mount has frequently been attributed to depression of the collodion when drying. Successful unshadowed pictures of the Camp Berthaux montmorillonite have recently been taken and show the irregular shapes and re-entrant angles mentioned by Méring (*Bull. Soc. franc. Miner. Crist.* **79** (1956), 515). (Nixon and Weir.)

Physical Chemistry of Soil Minerals

Interaction of water and clays

The energy distribution in such systems as kaolinite and water, where swelling is small, is being investigated to try to establish how adsorbed layers of water are related to bulk water. Evidence is accumulating that the film thickness at which the liquid-vapour interface can be said to resemble that obtained with bulk water is greater than has been previously supposed.

It has been shown that the suction of a non-swelling system is a

differential function of the liquid–vapour interfacial area, and hence the heat-of-immersion method can be used to measure pF. This method has now been successfully used down to a pF of 4, but at this stage there were difficulties because a variable blank heat breaks the thin glass containers. R. C. Gallavan has investigated the cause and remedy of this variability and found that a fixed composition of dissolved gases in the water used for immersion is necessary to maintain a constant blank heat of breaking. This combined with a new method for breaking the bulbs, and corrections for the degree of filling and the vapour pressure within the bulbs enables the blank heat to be predicted to $\pm 0{\cdot}01$ joule. To make use of this accuracy the calorimeter sensitivity has been increased four times, so that the temperature sensitivity is now 5 micro degrees per mm. deflection. Some of the less-satisfactory work is now being repeated, with a possible extension of the suction range measurable in conjunction with discontinuities in the build-up of thick water films on clays (*Rep. Rothamst. exp. Sta. for 1957*, p. 69).

Studies were continued on swelling clays such as montmorillonite, with which an appreciable amount of energy is associated with swelling and must be allowed for. The heat of immersion of montmorillonite samples plotted as a function of water content show inflexions directly related to the points where the interlayer water thickness changes. From these changes it is hoped to obtain data on the energy of swelling. (Greene-Kelly and Gallavan.)

Optical properties of clays

During the recent visit of R. Greene-Kelly on a Royal Society Exchange Fellowship to the Academy of Sciences, U.S.S.R., Prof. Deryaguin suggested that it would be of interest to study the optical properties of montmorillonite flakes in salt solutions and to deduce the optical properties of the interlayer water as a function of film thickness. The results obtained showed that the interlayer water when about 50 Å. thick, had a weak positive birefringence (i.e. of the same order as ice). At Rothamsted Greene-Kelly has continued his study of the optical properties of clays in two main directions with encouraging results: first, the measurement of the birefringence of organic complexes of montmorillonite previously studied by X-ray methods (*Rep. Rothamst. exp. Sta. for 1953*); secondly, an optical examination of different types of expanding and partly expanding clay minerals. A complex of montmorillonite and an organic compound has a birefringence which depends, among other factors, on the orientation of the molecule in the interlayer space. Thus, an isotropic complex can be prepared from a strongly negative silicate mineral and an equally strongly positive interlayer substance. This makes possible the identification of montmorillonite-like interlayer spaces from the optical properties of samples in different solvents, irrespective of the degree of disorder of the mineral. In this way the optical method can be considered a valuable supplement to the X-ray method, particularly when dealing with disordered minerals such as occur in soils. Various disordered mica-like minerals have already been examined with success. (Greene-Kelly.)

High-pressure synthesis of clay minerals

The setting up of the equipment has proved troublesome, but samples of clay minerals have been successfully synthesized. Specimens of the synthetic clay have been examined by X-rays, D.T.A. and electron microscopy and chemical analysis. The low angle X-ray-diffraction camera (*Rep. Rothamst. exp. Sta. for 1957*) was used to measure the degree of crystallinity of the products. Though there is much less central scatter from the synthetic material than from untreated gels, there is much more than from a well-crystallized natural kaolin. (Rayner.)

Spectrochemistry

Levels of trace elements present in certain English sedimentary deposits, in particular the Gault and Oxford clays and the Lower Greensand, are being studied with the object of relating them to the levels found in soils.

Earlier work on the Lower Lias shales has shown that abnormally high contents of Cu, Mo, Ni and V are related to the amount of bituminous material present. Samples of Oxford clay analysed have again shown that clays with high bitumen content contain larger amounts of these elements, but the enrichment is not as great as in the Lias. Whereas Mo levels of 200 p.p.m. were found in the Lias, the highest amount found in the Oxford clay was only about 20 p.p.m. The levels of Cr and V are in general higher in the Oxford clay than in the Lias or the Gault. The organic material deposited in both the Lias and the Oxford clay was probably potentially capable of accumulating Cu, Mo, Ni and V from the sea-water, and the differences between their present contents arise at least in part from different abundances in the water. The Gault clays examined were much less bituminous, and no evidence was found of enrichment of these elements in them. Apart from these differences, Co, Cr, Cu, Ga, Mn, Mo, Ni and V remained at fairly uniform levels in all three formations. No great variations in trace-element assemblages are likely to occur between similar soils derived from such rocks.

In the Lower Greensand the levels are in general much lower. Specimens ranging from consolidated sandstone to pure silver sand showed large differences in trace-element contents. The former, which contains far more iron oxide, is also much higher in trace elements, although the amounts are still small. It is therefore to be expected that soils on such materials will not only be low in trace elements but that their content will vary more than in soils derived from the clay sediments.

In this connection it is noteworthy that soils from Rothamsted gave consistently higher figures for Ba, Co, Cr, Cu, Ga, Mn, Ni and V than the Woburn soils. (Le Riche and Burnett.)

Soil Chemistry

Effect of soil waterlogging

Anaerobic incubation of a waterlogged soil to which dried grass was added caused part of the iron contained in the soil to become

extractable by a solution of ammonium acetate (*Rep. Rothamst. exp. Sta. for 1957*). The amount of iron thus mobilized increases with increasing organic matter up to about 20 per cent by weight of the soil. Increasing the organic matter to 30 per cent has relatively little effect on the amount of iron mobilized, although the maximum amount of iron extracted by ammonium acetate does not exceed about half the " free iron oxide " that may be removed from the soil by dithionate or similar treatment.

The solution of the oxides of some minor elements by decomposing plant remains was studied. Cu, Zn and Mn are very readily dissolved, Co and Ni less readily. Molybdenum, as molybdic oxide or as calcium molybdate, is virtually inactive; however, when ferric oxide prepared by precipitation in the presence of molybdate was used as the source of molybdenum, appreciable quantities were mobilized during incubation with dried grass. A similarly prepared co-precipitated material was used in testing the behaviour of vanadium, because vanadium pentoxide is appreciably soluble in water; here again, vanadium was mobilized. The effect with molybdenum may provide a clue as to the way in which this element becomes available in teart soils.

With all the elements studied, the mobilized material passed through cellophane on dialysis, so that the process involves true solution, and is not one of peptization.

Aeration of fermentation solutions of Cu, Zn, Mn, Co, Ni precipitates little or none of the particular element, but when fermented in the presence of ferric oxide, some of the trace element is carried down on aeration with the precipitated ferric oxide. Further, the minor elements are effectively sorbed from the fermentation solutions by ferric oxide. These observations are no doubt relevant to the fact that ferric oxide concretions, or laterite, commonly contain much more trace elements than the surrounding non-concretionary material.

Gleying decreases the total content of minor elements in a soil, but, for most of the trace elements at least, it increases the ratio of the readily soluble to the total amount of the particular element present. In agreement with this, whereas a minor element that has been sorbed on ferric oxide may not be removed by water, the greater part of the sorbed metal may be removed by treatment with a solution of neutral ammonium acetate. (Bloomfield, Greet and Siew Kee.)

SOIL MICROBIOLOGY DEPARTMENT

P. S. Nutman

R. Cooper went in June to spend a year at the Timiryazev Academy, Moscow. Miss G. Lim arrived on 1 September from the University of Malaya, Singapore, to study the influence of soil micro-organisms on the infection of legumes by nodule bacteria. R. M. Jackson has been awarded the Ph.D. degree of London University.

Dr. R. J. Swaby of the Division of Soils, Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia, spent two months in the department working on the red pigment formed in the leaves of certain ineffectively nodulated plants of subterranean clover. The pigment was shown to occur in small quantity in effectively nodulated plants. Chemically it differs from that of the seed testa and from a wide range of naturally occurring anthocyanins and anthocyanidins; it most closely resembles pelargonin. Mr. H. Fritsche of the Berlin Technical University, W. Berlin, helped N. Walker in the synthesis of halogenated aromatic compounds used in his work. The following visitors came for shorter periods: Mr. A. R. Azmi of the Atomic Energy Commission, Karachi, Pakistan; Mr. H. H. Louw of the University of Stellenbosch, South Africa.

Work on the biochemistry of the decomposition of the halogenated phenyoxyacetic acid herbicides, on the survival of bacteriophage of *Rhizobium* in artificial soil mixtures and on certain aspects of rhizosphere microbiology was ended. New lines of work started were on the microbial decomposition of pentachlorophenol, the detergent "Teepol", synthetic oestrogens added to soil, on the changes taking place in the microflora of the gut of three species of earthworm, on the influence of very small additions of nitrates to the earliest stages of nodule formation in clover and on genetic recombination in *Rhizobium trifolii*.

The anaerobic fermentation of cellulose

An anaerobic cellulose-digesting bacterium has now been isolated from soil in pure culture. Its cells are slender, Gram negative rods, 0·3–0·7 μ wide and 2–8 μ long, with terminal spherical spores about 1 μ in diameter. The organism is motile at some stages of growth, and produces acid and gas from several sugars, of which cellobiose is most readily used. Two types of colonies form on solid media; some small and compact, others diffuse and spreading. In deep culture in agar media, the spreading type of growth is the more active, especially in gas production. Spreading growth is suppressed by a low concentration of lithium chloride. Colony type changes readily and reversibly; it has not been possible to separate the two forms.

Studies on the decomposition of cellulose have been made in a mineral salt solution buffered at pH 7·0 in sealed nitrogen-flushed bottles containing finely divided cellulose, yeast extract and a reducing agent such as cysteine or sodium thioglycollate. At 35° C. bacterial attack on the cellulose particles becomes apparent about a week after inoculation, when coarse aggregates form from the cellulose flocculi which cohere to give a viscid mass. The bacteria are closely associated with the cellulose, so that the supernatant fluid at first remains clear, but becomes turbid when later the cells become motile. Digestion takes several weeks to complete, during which the pH falls from 7·0 to about 5·0, because formic, acetic and malic acids are formed. Hydrogen and carbon dioxide are also produced, but not methane.

Of the reducing sugar present in old cultures, glucose is probably the major constituent, but concentrates of culture filtrates have not yet been sufficiently purified to establish this beyond doubt; only trace quantities of cellobiose are present. *Clostridium cellobioparum* Hungate, a rumen organism, differs in this respect in producing cellobiose but no glucose in cellulose fermentation. However, as the Rothamsted isolate is very similar in other ways to *C. cellobioparum*, it is regarded provisionally as a strain of this species. (Skinner.)

The decomposition of anionic surface active agents by soil bacteria

A bacterium capable of using both primary and secondary alkyl sulphates as carbon sources has been isolated from local soil. The organism is a species of *Pseudomonas* as yet unidentified. In mineral salt solution containing 0·1 ml./l. of " Teepol 530 " (a secondary alkyl sulphate) growth is rapid and the surface tension of the medium rises from about 36 to 68 dynes/cm. in 48 hours. Ability of the liquid to foam on shaking is lost during this period. The organism also grows well in similar mineral medium containing 2.0 ml./l. " Teepol " (corresponding to *c.* 600 p.p.m. of the active constituent). Primary alkyl sulphates with alkyl radicals containing from ten to eighteen carbon atoms are also utilized. A number of detergents of the alkylolamide type also serve as carbon sources for this bacterium, but not tetrapropylene benzene sulphonate, an active constituent of some commercial detergent powders. Indeed, though many soil micro-organisms tolerated this persistent compound, none was found that could use it. (Skinner.)

The microbial decomposition of pentachlorophenol and di-ethyl-stilboestrol

Pentachlorophenol, which is used to proof fabrics against rots, is very resistant to attack by soil micro-organisms; no appreciable loss has so far occurred in enrichment culture maintained for 12 months. Pentachlorophenoxyacetic acid has been prepared, and its stability in soil is also being examined. Di-ethyl-stilboestrol, a synthetic oestrogen administered to cattle and poultry to promote live-weight increase, disappears rather slowly in incubated suspension of soil, presumably by microbial activity, though no isolates have so far been obtained which can use these substances in pure culture. (Walker.)

The influence of 2 : 4-D on the bacterial flora of Rothamsted allotment soil

The effect of various treatments with 2 : 4-dichlorophenoxyacetic acid on numbers and kinds of organisms occurring in Rothamsted allotment soil has been followed using the viable plate count to follow general changes occurring in the bacterial population and a dilution counting technique to follow changes in the micro-organisms able to break down 2 : 4-D. In the dilution count 2 : 4-D is added to each dilution in small amounts, and after incubation the cress seedling test is used to determine the end point of the disappearance of 2 : 4-D. A small dose of 2 : 4-D (50 p.p.m.) only slightly affects the total count and the number of organisms able to decompose 2 : 4-D, but larger doses (500 p.p.m.) considerably increase the latter. Earlier work with bacteria isolated from soil showed that the breakdown of 2 : 4-D is due to adaptive enzyme formation (*Rep. Rothamst. exp. Sta. for 1955*, 66), and again the adaptation of organisms in soil to breakdown of 2 : 4-D was induced by doses of 2 : 4-D (0·2 p.p.m.), far too small to cause detectable population changes.

Several new organisms able to decompose 2 : 4-D were isolated and classified into three main species: *Bacterium*, *Achromobacter* and *Pseudomonas*. (Steenson.)

The effect of earthworms on soil micro-organisms

Counting methods have been developed for yeasts, fungi, actinomycetes and various groups of bacteria occurring in the intestines of three species of earthworms: *Lumbricus terrestris*, *Allolobophora longa*, *A. caliginosa*. Results show that the numbers of bacteria and actinomycetes in the gut reach densities about 1,000× greater than in the surrounding soil, with maximum numbers occurring in the hind gut. The numbers of yeasts and fungi do not increase significantly. Preliminary investigations on the breakdown of cellulose and chitin in the intestine of *L. terrestris* indicate that enzymes produced by the worm rather than bacteria play a major role in these processes.

Counts of yeasts, fungi, actinomycetes and bacteria have been made on casts freshly produced by *A. longa*. Changes in the number and respiratory activity of micro-organisms have also been followed using casts aged under field conditions. Plate counts show that the numbers of yeasts and fungi in the casts increase rapidly in the first few days, and then remain fairly constant for a considerable time. Numbers of actinomycetes and bacteria do not change significantly. The rate of oxygen uptake by cast material is initially high and declines very slowly; it is still considerably higher than that of soil after 50 days. Total nitrogen in fresh casts is high, usually 5–6 mg./g. dry weight of cast. In freshly voided casts ammonia forms 90–98 per cent of the mineral nitrogen and 4–6 per cent of the total nitrogen. The rate of nitrification of this ammonia is being followed. (Parle.)

Nitrification

Further improvements have been made in the method of growing *Nitrosomonas*, notably by omitting minor elements in the medium

(Cu is found to be markedly inhibitory at 0·2 p.p.m.), and by determining the temperature and pH range for growth. Cell densities of about 2×10^8/ml. have now been achieved in 5-day cultures and sufficient cell material obtained for a preliminary spectroscopic examination. This has revealed high levels of substances with cytochrome absorption spectra. A continuous culture apparatus is now being installed for this work. Fresh strains of both *Nitrosomonas* and *Nitrobacter* are being isolated. (Walker and Meiklejohn.)

Nitrogen fixation by Azotobacter and Clostridium

Counts of *Azotobacter* on selected plots on Broadbalk were continued. Unless the full examination of the data shows any points on which further information is needed, it is not proposed to continue this study. The results obtained agree in the main with those of former years (*Rep. Rothamst. exp. Sta. for 1956*, 73 and *1957*, 76).

A method for counting nitrogen-fixing anaerobes in soil, adapted from that used by Hart, seems to give valid results, but it is very laborious. The few counts made confirmed earlier results, which showed that nitrogen-fixing anaerobes are more numerous than Azotobacter in the Broadbalk soils. (Meiklejohn.)

Nitrogen fixation by other free-living soil bacteria

Nitrogen-fixing bacteria other than *Azotobacter* and *Clostridium* are frequently found in appreciable numbers on plates of nitrogen-poor media and may play a significant part in the nitrogen cycle of the soil. Some strains were isolated which showed appreciable nitrogen fixation and a bacterium, probably *Aerobacter* sp., was selected for study. Nitrogen fixation by this strain is unaffected by ammonium salts and nitrates, but inhibited by amino acids. When soil, but no other combined nitrogen source is added to the mineral medium, nitrogen fixation is unimpaired, provided a substrate such as glucose is present; with no carbon supply no growth or fixation occurs. A start was also made on investigating the nitrogen-fixing power of these bacteria and of *Azotobacter* in mixed culture, and in the presence of the plant root. So far the results have shown that fixation in mixed culture is sometimes better. Most of the bacterial strains examined can fix as much nitrogen under conditions of reduced oxygen tension as with full aeration. (M. E. Brown.)

Soil fungistasis

Attempts were made to obtain fungistatic extracts from soil with dilute acids and bases, with solutions of salts such as sodium and potassium pyrophosphate, with sodium acetate, citrate and oxalate, and with organic solvents. Inhibitory activity was found with several extractants, but sterilization by passage through Ford Sterimats, sintered glass filters or by exposure to ultra-violet always removed the activity. The inhibition before sterilization is caused by bacteria which are active during the subsequent germination tests and can be eliminated by adding aureomycin to the assay agar.

Bicarbonate is being considered as a possible source of soil

fungistasis, and a study is being made of the effect of bicarbonate on the germination of the conidia of *Penicillium citrinum*. Concentrations as low as 0·005 per cent of potassium bicarbonate depress germination, but complete inhibition is not obtained until the concentration is increased to 0·5 per cent. Suitable methods for detecting and estimating bicarbonate diffusing into agar in contact with soil are being developed.

An examination of the redox potentials on the surface of agar discs incubated over soil revealed no significant differences from the potentials occurring on control agar discs which support germination. Over the range normally favouring germination, temperature does not influence soil fungistasis significantly.

Following the observation that seedling roots may stimulate germination of inhibited fungal spores in soil, exudates from germinating seeds and seedling roots have been examined for their effect on soil fungistasis and for the presence of substances likely to be responsible for stimulation. Exudates from peas 24 and 48 hours after germination stimulate germination of *Gliocladium roseum* conidia in the presence of soil and contain glucose, fructose and sucrose. Concentrated root exudates from older pea seedlings growing either in nutrient salt solutions or distilled water neither counteract soil fungistasis nor contain detectable quantities of sugars. Preliminary work on the factors influencing chlamydospore formation in a strain of *Fusarium solani*, an unidentified *Fusarium* and *Trichoderma viride* showed that they are formed by *Fusarium solani* much more often in dark than in light, but with the other two light has little effect. (Jackson.)

Phage-induced changes in Rhizobium

The partially effective strain obtained by bacteriophage, from the ineffective strain Coryn, when tested on seeds of late Montgomeryshire red clover gives rise to mixed responses with the tested plants, as previously reported. Numerous further isolations were made from single nodules on either effectively or ineffectively responding plants. These again failed to give a uniform response in symbiosis so that the source of this variation is being sought elsewhere. A test was first made of the effectiveness of a Coryn phage mutant upon fifteen selected families of red clover of very diverse origin obtained from P. S. Nutman. With five of these families a mixed response was obtained, as with commercial red clover. With seven families the response was wholly ineffective, and with three it was uniformly effective, showing that the source of variation lay in the host. Plant material for the full genetic analysis of this variation is being prepared. Work on formal bacterial genetics in *Rhizobium trifolii* has been started using standard methods. Initially this will concern the most convenient properties of the bacterium—phage resistance and antigenic constitution. At a later stage it is hoped to include bacterial characters of symbiotic significance. (J. Kleczkowska.)

The physiology of initial nodulation

Previous work (*Rep. Rothamst. exp. Sta. for 1952*, 62) showed that clover plants grown on agar slopes are stimulated to nodulate

earlier by preplanting the agar slopes with another clover plant that is removed before the test seedling is sown, and the effect was attributed to some substance secreted by the donor seedling. Further investigation has shown this explanation to be incorrect; the stimulation occurs because the preplant removes from the medium traces of nitrogen present as an impurity in the water supply. With completely nitrogen-free medium, no stimulation by preplanting can be detected in red clover, although small effects are sometimes found with other species; these are being further investigated.

As little as 2·5 p.p.m. of nitrate nitrogen (equivalent to 25 μg. N/seedling) delays nodulation of white clover by 2 days. This effect is also given by nitrite, but not by ammonium salts, asparagine or urea, all of which are assimilated by the host plant at about the same rate. Experiments in which nitrate was added to the medium at intervals showed that inhibition is closely related to uptake of nitrate by the root.

Nitrate has long been known to depress nodulation when used at concentrations normally employed in nutritional work, but at these levels it also occurs with ammonium salts.

The need for controlled environmental conditions has become increasingly urgent as the work on the physiology of nodulation has progressed. The above experiments were done in a small cabinet maintained in a cold room at fixed day and night temperatures and artificially lit with fluorescent and incandescent lamps giving about 1,000 f.c. at the leaf surface. These conditions were wholly satisfactory for red, white and subterranean clover and *Medicago tribuloides* but not for lucerne. Under these conditions of growth much better differentiation was obtained in bacterial strain effectiveness than in the glasshouse. (Gibson.)

Root-hair infection of clover by nodule bacteria

A detailed survey of root-hair infection in twelve small-seeded legumes has been completed. In all species except those very sparsely infected, infection takes place in two distinct stages, as previously reported for *T. repens* and *T. fragiferum* (*Rep. Rothamst. exp. Sta. for 1957*, 77). In both phases infection proceeds at an exponential rate, the initial rate being higher. The change in rate occurs at about the time the first nodules or lateral roots are formed. Very considerable variation has been noted in the site of origin of infection threads in the hair (apical or lateral), their mode of development and morphology; some of these differences are characteristic of host species.

Bacterial strains differ independently of host in the numbers of infection they induce upon the host. Infection threads are often arrested in their development in the root hair. In young seedlings the proportion of arrested infection threads is related to the intensity of infection. This proportion is high on very sparsely infected plants and decreases as the number of infections increases, to a minimum on seedlings infected at about twenty sites; thereafter the proportion of arrested threads increases progressively. The proportion of infection threads arising on lateral outgrowths of root hairs increases as the seedling ages, but is not otherwise related to infection density.

No infections have been observed in the root hairs of nodulated plants of *Lotus hispida, L. augustissimus* and *Anthyllis vulneraria.* (Nutman.)

The host genetics of symbiosis

Selected material of red and subterranean clover was tested extensively, further selections made and a comprehensive breeding programme completed. In red clover the work is directed towards the separation and genetic analysis of plant material which responds ineffectively with certain normally effective strains of bacteria. In subterranean clover the density of nodule formation on the root is the character under investigation. The results of this study will be reported after the next generation has been examined. (Nutman.)

BOTANY DEPARTMENT

D. J. Watson

P. C. Owen resigned in February to take an appointment at Levington Research Station. His work on crop growth in relation to soil water supply was continued by B. Orchard, who joined the department in March.

In September L. H. Fernando returned to Ceylon, after gaining the Ph.D. degree of the University of London.

Dr. Waclawa Potapczyk of the Biochemical Institute, University of Lodz, Poland, who holds a Rockefeller Foundation fellowship, joined the department in October. She is working on kinetin and nucleic acid metabolism, in collaboration with Margaret Holden of the Biochemistry Department.

The Post-Doctorate Fellowship of the National Research Council of Canada awarded to Gillian N. Thorne was extended for three months, and she spent the year in the Botany and Plant Pathology Laboratory of Science Service, Department of Agriculture, in Ottawa, working on plant growth in controlled environments.

Physiology of Leaf Growth

Factors that influence leaf growth, and affect the number, size and longevity of leaves are being studied in the laboratory because variation in yield of crops depends mainly on variation in leaf area. In particular, some substances that are known or are alleged to have growth-promoting properties have been tested on leaves, and an attempt is being made to extract from growing leaves substances that specifically influence leaf expansion.

Effect of gibberellic acid on leaf growth and net assimilation rate

In a previous experiment (p. 242, no. 5.6) when Majestic potato plants were sprayed with gibberellic acid (50 p.p.m. in water) twice with an interval of a week, the area of leaves on the main stem and lateral branches was increased. Net assimilation rate was only slightly decreased by spraying, so that, at the end of the experiment 4 weeks after the second spraying, the sprayed plants had more dry weight than the unsprayed. The additional weight was all in the tubers. However, the leaf area of sprayed plants at this time was decreasing more rapidly than that of the unsprayed, so it was doubtful whether the increase in dry-matter production would have persisted had the plants been allowed to continue growing. This was investigated in 1958, when unsprayed plants were compared with plants sprayed twice with gibberellic acid, and also with others that received four additional sprayings at weekly intervals (six in all) to see whether prolonged spraying had more persistent effects on leaf area and dry-matter production. The spray treatments were tested on plants with a low or a high nitrogen supply. The plants, grown in pots from small sets each with a single eye, were first

sprayed when the lower lateral branches on the high-N plants were just beginning to elongate; the low-N plants produced no lateral branches.

At a harvest 3 weeks after spraying began, total dry weight per plant was already increased by gibberellic acid, though not significantly in the low-N plants. As in the previous experiment, the initial increase in dry weight was wholly in stems and leaves, and the weight of tubers was decreased. In the high-N plants spraying decreased the tuber weight to one-quarter of that of the controls, but had a smaller effect on low-N plants. The decrease in tuber weight was much greater than in the previous experiment, although the first harvest was made at a later stage of growth.

At the second harvest, 5 weeks after the first spraying, the dry weight of sprayed plants with the higher nitrogen treatment was about 10 per cent above the controls; all parts of the plant except the roots were increased in weight. In contrast, spraying decreased the dry weights of all parts of the low-N plants.

At the final harvest, 8 weeks after spraying began, high-N plants that had only two sprayings still maintained a greater dry weight than unsprayed plants, but the dry weight of plants sprayed six times was the same as that of the controls. Both spraying treatments decreased the dry weight of low-N plants. These results show that the effectiveness of gibberellic acid depends on both time and frequency of application, as well as on nitrogen status of the plants.

Gibberellic acid increased the areas of leaves both on main axis and lateral branches, especially of low-N plants. At the first harvest the total leaf area of these plants was increased by 40 per cent, and additional sprayings after the first produced no extra increase, though it accentuated the symptoms of nitrogen deficiency. In high-N plants the four additional sprayings after the first two gave a further small increase in leaf area, mainly in terminal leaves of the main axis and on lateral branches.

The number of leaves on the main axis was not affected by gibberellic acid except that, on the high-N plants sprayed six times, small leaves were produced on the terminal inflorescence.

The axillary shoots of the high-N plants were largest at the lower nodes of the main shoot, and were smaller at intermediate nodes than at the upper ones. Spraying with gibberellic acid increased the leaf area of the upper and lower branches, but greatly decreased the area and number of leaves on the branches at nodes 10 and 11. The size of leaves on the main axis was maximal at about node 14, so the restricted growth of the axillary shoots at nodes 10 and 11 may be from competition for nutrients with developing branches below them and expanding leaves above them. If so, this competition was enhanced by gibberellic acid.

The net assimilation rate of unsprayed plants was independent of nitrogen supply. Spraying with gibberellic acid greatly decreased the net assimilation rate of low-N plants, so that in spite of increased leaf area less dry matter was produced. The decrease was smaller in high-N plants and was not significant. (Humphries.)

Effect of ascorbic acid on leaf growth

It has been reported * that ascorbic acid promotes leaf growth and accelerates flowering of some plants, including Chinese cabbage (*Brassica chinensis*). Experiments repeating precisely the conditions in which ascorbic acid was said to be effective failed to confirm the effect. Ascorbic acid solutions freshly prepared every hour were applied to cotton-wool wrapped round the growing point. Other plants were sprayed with ascorbic acid solution. Both methods of application slightly inhibited the growth of the two youngest leaves unfolding at the time of treatment, but had no effect on subsequent leaves or on time of flowering. (Humphries.)

Biological assay of leaf growth-substances

Gibberellic acid (GA) and kinetin (K) affect leaf growth (p. 242, nos. 5.5 and 5.6), and these substances were used to examine the suitability of biological tests for assaying growth substances extracted from leaf tissues. Both GA and K were active at concentrations of $10^{-5}M$ and $10^{-6}M$ in the wheat-coleoptile-section and etiolated-pea-epicotyl-section tests, which have long been used to assay 3-indolylacetic acid (IAA) and related auxins. They both promoted extension growth of wheat coleoptile sections, but less than did IAA. Growth of pea epicotyl sections also was accelerated by GA, but was slightly inhibited by K. In neither test was there any interaction of GA and K; their effects appeared to be additive.

To measure activity in promoting leaf expansion, an assay method based on the growth of leaf tissue is obviously essential, and etiolated primary leaves of 6-day-old " Selected Canadian Wonder " dwarf-bean seedlings grown in darkness at 25° C. were used. Disks 6 mm. in diameter were cut from the leaves in a dim red light, and floated on the test solution containing 1 per cent sucrose, with the adaxial surface in contact with the solution. After 24 hours in darkness at 25° C., the increase in diameter of the disks was measured. This test confirmed that GA and K both accelerate leaf expansion. At concentrations of 10^{-5} or $10^{-6}M$ their effects were less than that caused by fluorescent light of 400 f.c. intensity. The effect of K was eliminated in the presence of light, but that of GA was slightly increased. Light and GA had much smaller effects when the abaxial surface of the disks, instead of the adaxial, was in contact with the solution, presumably because the stomata were blocked. GA was less effective with no sucrose in the solution. Usually a vein formed a diameter of a disk, and IAA (10^{-5} or $10^{-6}M$) caused no expansion in a direction perpendicular to the vein, but increased the length of the vein, and consequently the disks rolled up in the form of cylinders. This effect of IAA in promoting the growth of the veins but not the lamina is well known.

To reduce the variability of the test, the bean seeds were graded by weight before planting. The test was more sensitive to GA with small seeds, which suggests that large seeds supply more GA, or related substances, to the primary leaves, but this has not yet been

* Chinoy, J. J., Nanda, K. K. & Garg, O. P. (1957). *Physiol. Plant.* **10**, 869.

confirmed by assaying extracts of the seeds. The growth-promoting effect of K appeared to be independent of seed size.

Ascorbic acid, reported by other workers to promote leaf expansion (p. 77), was inactive in the leaf-disk test at a concentration of $10^{-4}M$, and inhibited expansion of the disks at $10^{-3}M$. Carbanilide (1 : 3 diphenylurea, the coconut milk factor of F. C. Steward) slightly increased the growth of the leaf disks and had its maximal effect at $10^{-3}M$. (Wheeler.)

Growth substances extracted from primary leaves and cotyledons of dwarf bean

Dwarf-bean plants were grown in a light intensity of about 950 f.c. from fluorescent tubes, supplemented by red and infra-red radiation from incandescent ballast lamps to prevent stunting. Plants were removed at various stages of growth and their primary leaves extracted with ethyl acetate. The extracts were partitioned with dilute acid or alkali to separate basic and acidic substances, and finally fractionated by paper partition chromatography, using ammoniacal *iso*propanol solvent. The chromatograms were cut into segments which were assayed by the etiolated-dwarf-bean-leaf-disk test. A zone of growth activity with an R_F value similar to that of a marker GA spot occurred consistently on chromatograms of leaf extracts containing acidic substances. The activity of this zone was highest for extracts of primary leaves made at the stage when they were expanding most rapidly. More growth activity was found on chromatograms of an extract of bean leaves grown in light than on those from an extract of a similar number of leaves grown in darkness. Zones of growth activity with a similar R_F value were found also on chromatograms of cotyledon extracts containing acidic substances. These results suggest that GA, or similar substances, is a normal constituent of bean leaves, and that its presence is related to leaf expansion. (Wheeler.)

A method of estimating the number of cells in leaves

The number of cells in a plant tissue can be estimated either by direct counting on cleared preparations under the microscope or by disintegrating the tissue and counting the cells in a suspension on a haemocytometer slide. The usual method of disintegration is to digest the tissue with chromic acid, but this may give misleading results with leaf tissue, because some cells may be completely digested and the estimated number may decrease with time of digestion. A somewhat gentler technique has therefore been developed, in which leaves or leaf disks are incubated with pectinase preparations in the presence of the disodium salt of ethylene-diamine-tetracetic acid (EDTA). The EDTA greatly facilitates the separation of leaf cells, possibly by chelating the calcium of the calcium pectate in the middle lamella. The method works well with dwarf-bean and tobacco leaves, but is not applicable to every kind of leaf, e.g., with holly and ivy the lower and upper epidermal cells are separated as sheets of cells, while with leaves of grass or barley no breakdown appears to occur. An investigation of factors affecting cell numbers in leaves of dwarf bean has been started. Primary leaves of plants grown at 20° C. in a 12-hour daily light

period each had approximately 3×10^7 cells; complete darkness apparently prevented the last cell division because leaves of plants grown in the dark had only about half this number of cells. (Humphries.)

Mode of action of kinetin and gibberellic acid on leaf expansion

The method of counting free cells in a suspension of leaf-tissue digested with pectinase in presence of EDTA was used to investigate how gibberellic acid and kinetin influence leaf expansion. Cell counts were made on disks of etiolated primary leaves of dwarf bean, treated with GA or K in the same conditions as were used to assay effects on leaf expansion (p. 77). K appeared to increase the numbers of cells in darkness, and to decrease the number in light. The effect of K on cell number was smaller than that of fluorescent light of 400 f.c. intensity. GA had no effect on cell number; implying that it increased leaf expansion solely by increasing the size of cells. (Humphries and Wheeler.)

Growth promotion by pectinase preparations

A pectinase preparation in dilute solution was effective in promoting extension growth of wheat coleoptile and pea epicotyl sections. It was more effective with EDTA at 10^{-3} or $10^{-4}M$. A similar mixture of pectinase and EDTA had only a slight, but significant, effect on expansion of leaf disks. Current theories of the structure of the cell-wall and cell expansion suggest that the growth-promoting effect of pectinase may be attributable to increased plasticity of the cell-wall brought about by breakdown of pectin. (Wheeler.)

Growth Analysis

The effect of soil moisture deficit on plant growth

During a prolonged drought period in 1955 the leaf-area index (L) and net assimilation rate (E) of an unirrigated sugar-beet crop at Woburn were both much below those of a crop irrigated to maintain minimal water stress, but after a little rain, much less than the estimated water deficit, the relative leaf growth rate and E were greatly increased and rose above those of the continuously irrigated crop, so that temporarily the unirrigated crop produced dry matter at a greater rate than the irrigated crop (*Rep. Rothamst. exp. Sta. for 1955*, p. 77). An attempt was made to reproduce this effect at Rothamsted in 1957 with a sugar-beet crop protected from rain by a Dutch-light glasshouse, so that the whole water supply was under control (*Rep. Rothamst. exp. Sta. for 1957*, p. 89). Three treatments were compared: (*a*) continuous irrigation, (*b*) drought interrupted by a single large application of water, and (*c*) drought interrupted by frequent small applications. The crop receiving (*a*) had a higher L throughout, and consequently produced a higher yield of dry matter. Immediately after the waterings in treatments (*b*) and (*c*), E was a little higher than for treatment (*a*), but the effect was always much less than that of rainfall after drought in the Woburn field experiment, and the rate of dry-matter production per unit area of crop was always greater for (*a*) than for (*b*) or (*c*).

Another experiment was done in the Dutch-light glasshouse in 1958, comparing the following treatments:

(*a*) *Minimal water stress* maintained by frequent waterings.

(*b*) *Early drought.* The plants were subjected to three drought cycles during June and July, and at the end of each cycle the plots were watered just before permanent wilting point was reached (in the top 12 inches of soil). At the end of the drought period the water deficit was 6 inches. During August and September the plots were watered as for treatment (*a*).

(*c*) *Late drought.* The plots were watered as for (*a*) until the end of June, and then received no water, except for 1 inch applied in late September. The water content of the soil (to 12 inches depth) was constant at about permanent wilting point (14 per cent) during August and early September.

All the plots were watered uniformly until the beginning of June, when the drought periods of treatment (*b*) began. After that, the total amounts of water applied were: (*a*) 14 inches; (*b*) 10 inches; (*c*) $5\frac{1}{2}$ inches. To reduce variability between plants, sugar-beet seedlings were raised in soil blocks and selected for uniformity before planting out in early May. Samples of plants were taken on six occasions between the beginning of July and the end of September.

By the end of July, plants that had suffered the early drought of treatment (*b*) had a slightly lower dry weight than the others, and this was wholly due to a decrease in L, for E was unaffected. However, in the fortnight after watering was resumed at the end of July, E for treatment (*b*) was higher than for the others and L also increased, whereas it decreased for treatment (*a*). Throughout August and September, L of treatment (*c*) fell steadily below that of treatment (*a*), which remained nearly constant. All the effects of drought on L were the result of decreased leaf expansion, because leaf number per plant was unaffected. Watering of the (*c*) plots in September after the prolonged drought period had no detectable effect on E or L. At the final harvest the dry-weight yields for treatments (*a*) and (*b*) were similar, but that for treatment (*c*) was slightly less. Statistical analysis of these results is not yet completed, and the significance of some of the effects mentioned is uncertain.

Thus, there is evidence that watering after the early drought period, but not after the late drought, produced a spurt of growth involving temporary increases in both E and relative leaf-growth rate similar to, but much less than, that observed in the field at Woburn in 1955. The reason for watering after drought in the 1957 and 1958 experiments at Rothamsted producing so much smaller effects than at Woburn is not yet known; it may depend on differences in soil or in seasonal weather. The lack of response to the watering in September of sugar beet previously unwatered since the end of June may be because the roots were then actively absorbing only from lower depths of the soil, and had become almost independent of treatments applied to the surface. (Orchard.)

Measurement of the CO_2 *flux of a field crop*

An attempt is being made by J. L. Monteith, of the Physics Department (see p. 38), to determine the flux of CO_2 into a field

crop through photosynthesis in the light, and out of it from respiration in the dark, by measuring continuously the gradient of atmospheric CO_2 concentration immediately above the crop. If the estimates are valid, they should, when integrated over a suitable period, conform with the increase in dry weight of the crop. To test this, samples were taken at intervals from the sugar-beet crop to determine the changes with time in its yield of dry matter. Leaf-area index was also measured, so that the magnitude of the CO_2 flux can be related to the size of the photosynthetic system. The physical and biological measurements agreed well for early periods of growth, but the calculations for the later periods are not complete. (Orchard.)

Measurement of leaf area

An instrument has been developed for measuring the areas of sugar-beet leaves in the range from 10 to 1000 sq. cm. by a scanning method. The leaf is placed against a white background and a light beam, interrupted by a shutter, is made to traverse the background and the leaf by means of a rocking mirror. The mirror is moved forward between each traverse in the direction at right angles to the scanning direction, so that the whole area of the background is scanned once. Pulses of light reflected from the background, but not from the leaf, are perceived and amplified by a photomultiplier, subtracted electronically from the total number of pulses sent out, and the result counted by a scaler. In effect, the instrument is made to count the pulses that are not reflected. A single pulse corresponds to 0·5 sq. cm. of scan.

Pulses which fall on the edge of a leaf can give rise to errors, which have been minimized by making the scanning spot cover approximately half the width of the unit scan in each dimension, and adjusting the instrument to count any pulse which just touches the leaf as fully on the leaf. If the disposition of the pulses with respect to the leaf edge is random, there is a probability of 0·5 that a unit scan falling symmetrically on the boundary will be counted, and this probability will increase as more of the unit scan falls on the leaf and vice versa. Good compensation for the edge effect has been achieved; if the error it causes were appreciable it would cause curvature in the relation of area to counts, but no such curvature was found. This source of error makes the instrument unsuitable for measuring small, divided or narrow leaves.

The standard error of a single determination, based on repeated measurements of test areas between 8 and 384 sq. cm., was 3 per cent of the mean. Leaves that will lie within a rectangle of 50 × 30 cm. can be measured, and can be scanned in 10 seconds. The instrument is suitable for routine use in its present form, but requires careful adjustment and shows instability while warming up. Some of its present defects can be avoided by slight changes in construction, and it is hoped to develop similar instruments suitable for small, dissected and narrow leaves, and possibly for field use. (Orchard.)

Net assimilation rate of cultivated and wild beet

Further examination of data collected in 1956 comparing net assimilation rates (E) of wild sea beet (*Beta vulgaris* subsp. *maritima*)

and Kleinwanzleben sugar beet (*Rep. Rothamst. exp. Sta. for 1956*, p. 86) showed that, although the wild and cultivated beet had the same E when the leaf area index (L) was near to 1, they differed in E when L was larger. There was an inverse relation between E and L for the three wild beet types tested, similar to that previously found between strains of sugar beet. In a period when mean L for sugar beet was about 2·5, its E was much greater than that of the leafiest wild type, for which L was also about 2·5, but was little different from that of the wild type with the smallest L (about 1·5). This suggests that the development of sugar beet from its wild ancestors by selection and breeding has not affected the intrinsic photosynthetic efficiency of the leaves, but has improved the photosynthetic performance of the plants in another way; it has diminished the effect of mutual interference between leaves so that when they are crowded together their mean efficiency in dry-matter production is not so much impaired. This change is probably related to the form of the plant; the wild-beet plants had a prostrate habit, with leaves overlapping more than in sugar beet, the leaves of which are more nearly upright, so that they shade each other less and tend to receive direct sunlight over a larger fraction of the total leaf surface. If this interpretation is correct, it provides an example of the great importance of the spatial disposition of leaves, as well as their total area, in relation to yield. (Watson and Witts.)

Varietal differences in barley

In a comparison of field crops of Plumage Archer, Proctor and Herta barleys * no differences between the varieties were found up to the time of ear emergence in leaf-area index, total yield of dry matter or net assimilation rate, and after ear emergence, the leaf-area index of Plumage Archer was about the same as that of Proctor and greater than that of Herta. It was therefore concluded that Proctor and Herta produced higher grain yields because their ears photosynthesized more than did those of Plumage Archer. Increased total photosynthesis by the ears could result from an increase in their photosynthetic capacity, in their photosynthetic efficiency or both. Assuming that photosynthetic capacity is correlated with the size and weight of the parts of the ear other than the grain, any increase in it, without change in total dry weight of the crop at ear emergence, implies an increase in the ear : shoot dry-weight ratio. There was evidence of such a difference between varieties in ear : shoot ratio in the field at harvests after ear emergence, but this was complicated by differences in growth of the grain associated with varietal differences in time the ear emerged. To avoid this complication the ear : shoot ratio for the different varieties should be measured not on the same date, but at comparable stages of development and when the weight of grain is negligible, viz., at the time when the ears are beginning to emerge, or at anthesis. Such measurements have now been made on the main stem and first two tillers of plants grown in pot culture.

When ears start to emerge and at anthesis, the ear : shoot dry-weight ratios for Proctor and Herta were consistently slightly less

* Watson, D. J., Thorne, G. N. & French, S. A. W. (1958). *Ann. Bot.* N.S. **22**, 321–352.

than for Plumage Archer, although at maturity this difference was reversed and the ratio was higher for Herta and Proctor, as in the field experiment. This suggests that the greater dry-matter production by the ears, which seems to be responsible for the superior grain yield of Proctor and Herta, is not attributable to greater photo-synthetic capacity of the ears, though the survival of a higher proportion of shoots of Proctor and Herta than of Plumage Archer to form mature ears may produce more photosynthetic tissue in the ears on unit area of land.

The reversal of the varietal difference in ear : shoot ratio between anthesis and maturity implies that the increment in ear dry weight in this interval per unit dry weight of ear at anthesis was greater for Proctor and Herta than for Plumage Archer. If dry weight at anthesis is a valid measure of the photosynthetic capacity of an ear, this result suggests that ears of Proctor and Herta have a higher photosynthetic efficiency than those of Plumage Archer. (French and Watson.)

Weed Studies

Previous lines of work on weed problems have been continued, and work has been started on the nature and intensity of competition between crop and weeds.

Wild Oats

Survival of seeds under temporary ley and in cultivated land. On plots ploughed in autumn 1957 after three years under grass in the experiment at Rothamsted on survival of seeds of *Avena fatua* in land under temporary ley (*Rep. Rothamst. exp. Sta. for 1956*, p. 80 and *1957*, p. 92) only 1·2 wild oats seedlings per sq. yd. were counted in spring 1958, compared with 3·9 per sq. yd. in 1957 on plots ploughed after two years under grass. This may not indicate a decrease in viable seeds, because grass regenerated on the newly ploughed plots, so that it was difficult to distinguish the wild oats seedlings, and some may have been missed. Also, the grass may have partly suppressed the germination of wild oats. Fortunately, this can be tested in 1959, after the plots ploughed in autumn 1957 are reploughed; any seeds held dormant under the grasses should then germinate.

From soil samples taken from the field in Northamptonshire with a mixed infestation of *A. fatua* and *A. ludoviciana* that has been under ley for 4½ years, wild oats seeds were recovered by washing through sieves in numbers representing over 4 million/acre; there was no apparent change since 1957. The husks of these seeds were so decayed that the species could not be identified. Previous experience indicates that recognizable seeds in this condition and of this age are still viable, and some germinated during the handling of the soil samples. The viability of the remaining seeds will be tested on samples to be taken in 1959.

In the field at Bishop's Stortford where stubble-burning in autumn 1957 stimulated germination of a small part of the popula- of wild oats, mainly *A. fatua* (*Rep. Rothamst. exp. Sta. for 1957*, p. 93), peas were sown after several spring cultivations, but became

so thickly infested with wild oats that the crop was cut green for silage before the wild oats shed seed. This treatment greatly decreased the number of wild oats seeds in the soil; in October 1958, the top 6 inches of soil contained 24 seeds/sq. ft., only 3 per cent of the number present a year earlier. Subsoil samples from 10-inch depth had as many seeds as the surface soil. The husks of the remaining seeds were too badly rotted to identify the species; their viability is being tested, and some have already germinated.

Types from other countries. Samples of wild oats were received for identification from widely separated places, and some have been grown to see how they compare with the British ones. They included four types of *A. fatua* from Canada, one of *A. ludoviciana* from Greece and four sorts not found in Britain—*A. sterilis* var. *maxima* from Algeria, *A. sterilis* var. *scabriuscula* from Malta, *A. sterilis* subsp. *trichophylla* var. *calvescens* from Arabia and *A. barbata* from Malta. Seven British types of *A. fatua* and six of *A. ludoviciana* were also grown. Chitted seeds were planted in pots in the glasshouse at the end of December.

The Greek *A. ludoviciana* was less prostrate in the early stages of growth than its British counterpart, but the Canadian *A. fatua* were like the British ones in vegetative growth. *A. barbata* had a very prostrate habit, even after ear emergence. The Arabian variety of *A. sterilis* differed from all the others in having very short stems and many more ears per plant.

Ear emergence of *A. sterilis* began in early April and was completed in all but one of the foreign sorts by the end of the month; in one of the Canadian sorts of *A. fatua* it did not start until mid-May. In the British sorts it occurred between mid-May and early June. The early date for the Mediterranean types probably represents their normal time of flowering—the wild oats seeds from Malta were collected in the field in May, but Canadian wheat-lands are still frozen in April, when our plants grown from Canadian seed were flowering. Canadian conditions have apparently selected types with a short growth period, and this is evidently independent of whether the growth period includes the short days of an English winter or the long days of Canadian summer. The Canadian types of *A. fatua* produced about the same number of seeds as the similar types found in Britain, but many fewer than the commonest British types, which were not represented in the Canadian samples.

Seeds produced by the British and Canadian types of *A. fatua* showed a similar degree of dormancy, with about 10 per cent germination by late November. The germination behaviour of seeds of *A. sterilis* was similar to that of *A. ludoviciana*; most of the first seeds of spikelets could germinate soon after harvest, but second and subsequent seeds had a progressively higher percentage of dormancy and started to germinate later. (Thurston.)

Effect of combine-harvester on distribution of weed seeds

Samples of wheat grain, weed seeds and rubbish were taken from the three delivery spouts of the combine-harvester during harvest of selected plots of Broadbalk field. Samples of the straw and chaff thrown out by the combine on the plots were collected on a cloth drawn behind the machine. On other parts of the plots where

straw and chaff were allowed to fall on the ground and were subsequently picked up by a baler in the usual way, samples were taken of the material recovered by the baler. These samples made it possible to estimate the proportions of seeds of different weed species that are bagged up and carted off the field, either as rubbish or with the grain, or removed in the baled straw and, by difference, the proportion that remains on the ground after passage of the baler. The same samples are being used by the Chemistry Department to determine the amount of chaff left behind on the plots. Separation of the weed seeds from the samples is not yet finished.

The samples take no account of weed seeds shed directly on the soil before harvest, and the amount of this is likely to be different for harvest by combine and by binder, because with a combine the crop is cut at a later stage of maturity. Analyses of *Vicia sativa* seeds in the grain fraction, undertaken to see whether grain yield can be recorded with sufficient accuracy as the weight of the grain fraction or whether cleaning or sampling for purity is essential, show that it is not necessarily the plots with the heaviest infestation of *Vicia* that give the highest proportion of *Vicia* seeds in the harvested grain, because the amount of seed shed before harvest also depends on when the *Vicia* plants mature. (Thurston.)

Weeds of Broadbalk

A survey was made as usual of the weeds present on Broadbalk in May and after harvest. A detailed study of the poppies (*Papaver* spp.) in June, when they were flowering and had a few seed-pods, showed that *P. rhoeas* and *P. argemone* were abundant, but no *P. dubium* was found. This agrees with observations in recent years, but conflicts with an earlier report * that though *P. rhoeas* is the commonest poppy " a certain number of other species occur, chiefly *P. dubium*. *P. argemone* is also known to occur occasionally on the field ". *P. dubium* has not been found on Broadbalk or elsewhere on the Rothamsted farm in the past 15 years.

The records for the past 30 years show that the amount of *Alopecurus agrestis* (black bent) present in the crop at harvest tends to increase when the crop is sown early, before about 23 October, whereas sowing at the end of October or in early November maintains the infestation at its previous level, and later November sowing decreases it. This is presumably because *Alopecurus* finishes germinating for the season in about the second week of November, but as yet there are no field data to confirm this. In pans of field soil brought into the glasshouse the species germinates chiefly in autumn.

A special survey was made of Section 1a, where continuous cropping with wheat has been resumed and weeds are controlled by herbicides, to compare with Section 1b which remains in the fallowing cycle, and soil samples were again taken to measure changes in the weed-seed population. The herbicide (CMPP) was especially effective on plots 3 and 5, which receive no nitrogenous fertilizer and are heavily infested with *Vicia sativa* (vetch) and *Medicago lupulina* (black medic). Elimination of competition by these weeds nearly doubled the yield of wheat, but over a period of years

* Brenchley, W. E. & Warington, K. (1930). *J. Ecol.* **18**, 235.

eradication of leguminous weeds may impoverish the soil in nitrogen and make yields decline. (Thurston.)

Competition between crop and weeds

Survey of competitive effects of common weed species. A series of pot experiments is projected to compare the effects of common annual weeds on the growth of crop plants. In the first of these, plants of kale or sugar beet were grown in pots alone or with *Chenopodium album* (fat hen), *Stellaria media* (chickweed) or *Capsella bursa-pastoris* (shepherd's purse). Crop and weed seeds were sown on the same day in May, and the seedlings were thinned to one crop plant and 16 weeds per pot (about 1 per 2·5 sq. in.). Pots were also set up with the same number of weeds but no crop plant, and two rates of nitrogen supply were tested with each combination of crop and weed. At harvest 10–11 weeks after sowing, fresh and dry weights were determined for both crop and weeds, and also the leaf area of the crop.

Of the three weed species, *Chenopodium* decreased crop growth most; its effect on the relative growth rate of sugar beet was three to four times that of *Stellaria* or *Capsella*. Kale was much less susceptible than sugar beet to competition from *Chenopodium* or *Stellaria*, but there was little difference between crops in the effect of *Capsella*. Conversely, kale depressed the growth of weeds more than sugar beet did, and the effects of both crops on *Chenopodium* was less than on *Stellaria* or *Capsella*.

It was hoped that the interactions between weed effects and nitrogen supply would throw light on the causes of competition, but most of these interactions were not statistically significant. Leaf growth of sugar beet was depressed by *Chenopodium* or *Stellaria* more at the higher rate of nitrogen supply, suggesting that competition depended on factors other than nitrogen. The water content of kale leaves was unaffected by weed competition, but that of sugar-beet leaves was decreased by *Stellaria* and still more by *Chenopodium*, so that in spite of liberal watering, there may at times have been competition for water between sugar beet and weeds.

The presence of *Chenopodium* decreased the total nitrogen content of sugar beet to about one-tenth of that of plants without competition; *Stellaria* and *Capsella* approximately halved it, at both rates of nitrogen supply. A positive correlation was found between mean log. total nitrogen content of sugar beet and mean log. dry weight of roots for different treatments within each rate of nitrogen supply, but increased nitrogen without weed competitors *decreased* the root dry weight, although it increased the total nitrogen content of the plants. A possible interpretation is that the effects of competition were the result of changes in root growth which determined the differences in nitrogen uptake, and were not wholly due to depletion in nitrogen supply. Similar results could not be got with kale, because the roots could not be separated from weed roots in the mixed cultures. The total yields of dry matter per pot in mixed cultures of kale or sugar beet with weeds was increased by higher nitrogen supply relatively more than those of crops or weeds growing alone. This indicates that some direct competition for nitrogen was involved. (Welbank.)

Competitive effects of Agropyron repens. A more detailed study was made of the effects of *Agropyron repens* (couch grass) on the growth of young sugar-beet plants, and their dependence on nitrogen and potassium supply. If *Agropyron* competes for these nutrients and so lowers the amounts available to the crop, the effects on the crop should be less when the supply of nutrients is high than when it is deficient. To test this, sugar-beet seedlings at the four-leaf stage were transferred without disturbing their roots into pot cultures of *Agropyron* grown from rhizome sections of a single clone, and comparable cultures of sugar beet alone or *Agropyron* alone were also set up. All three types of culture were then treated with all combinations of three rates of nitrogen and three rates of potassium supply. Plants were harvested at the time of transplanting, and 2 weeks later; fresh and dry weights and leaf areas were determined for growth analysis, and nitrogen, phosphorus and potassium contents are being determined. Statistical analysis of the results are not yet complete; preliminary inspection suggests that competition for nitrogen or potassium affected the test plants only when the other nutrient was present in excess. (Welbank.)

Production of toxic substances by Agropyron repens. Since Osvald * showed that extracts of dried roots and rhizomes of *Agropyron repens* (couch grass) inhibit germination of rape and oats, many people have held that the competitive effects of *Agropyron* partly come from toxic substances produced in the soil. However, in experiments at Cambridge no evidence of toxic action was found. Inhibiting effects of dried and ground material may have little bearing on production of toxins *in vivo*, and experiments were therefore done to test directly whether living roots and rhizomes produce substances that inhibit germination and growth.

Wheat, barley, kale and tomato plants were grown in nutrient solutions, and during the experimental period were transferred on alternate days from this solution either to a leachate of *Agropyron* roots and rhizomes, or to distilled water as control. The leachates were prepared from *Agropyron* plants grown in nutrient solution by placing the plants with their roots and rhizomes in a shallow tank of distilled water, after washing to remove nutrient solution.

The leachate had no effect on wheat or barley after treatment for 3 weeks, and after 4 weeks it *increased* the dry weight and leaf area of kale and tomato plants. This was thought to come from leaching of nutrients from the grass roots and rhizomes, and in subsequent experiments nutrient solution was added both to the leachate as prepared previously and to the distilled water controls in the same concentration, and the solutions were renewed daily. After treatment for 4 weeks, there were no significant effects on tomato, but again the leachate increased dry weight and leaf area of kale. The explanation of this growth-promoting action is not known. Certainly no evidence of any toxic effect was found in these conditions, but in soil a toxin might be produced by action of micro-organisms on exudate from *Agropyron* roots. To test this, leachate prepared as above was watered daily on to pot cultures of kale plants in a fertile or an infertile Rothamsted soil, or in Woburn soil. After 4 weeks, the leachate had no significant

* Osvald, H. (1947). *Växtodling*, **2**, 288–303.

effects; the dry weight of plants grown in the poor Rothamsted soil was slightly decreased, but not in the others.

In another series of experiments, when chitted seeds of turnip or rape were placed on filter-paper held in contact with attached *Agropyron* roots kept moist with distilled water, the length of the radicle of turnip was increased by 30 per cent, and of rape by 15 per cent, compared with those of control seeds in similar conditions without *Agropyron* roots. Radicle growth might be stimulated by diffusion of ions out of the free space of the roots, or by secretion of elaborated organic compounds. The fact that replacement of water around the roots by a nutrient solution decreased the stimulation of radicle growth favours the former explanation, but chemical and spectrographic tests have so far shown only that sodium concentration was higher in the controls. *Agropyron* roots slightly inhibited hypocotyl growth, which appeared to increase with increasing strength of the nutrient solution.

The absence of any marked inhibitory effect of *Agropyron* roots or root leachates in these experiments indicates that the secretion of a toxin probably plays little part in the competitive effect of this species. Experiments are being made to see whether a toxin is produced when *Agropyron* decays in the soil. (Welbank.)

Effect of competition with Agrostis gigantea *on response of wheat to nitrogenous fertilizer.* Observations on a field experiment on winter wheat at Woburn in 1956 suggested that late nitrogenous top-dressing was less effective than early because an infestation of *Agrostis gigantea* harmed the crop more when the nitrogen supply was delayed. A pot experiment in 1957 did not wholly support this explanation (*Rep. Rothamst. exp. Sta. for 1957*, p. 93). Another pot experiment in 1958 compared spring wheat grown alone in Woburn soil with wheat grown in presence of *Agrostis* raised from rhizome cuttings, without nitrogenous fertilizer, or with nitrogen applied at two rates at the time of sowing or 7 weeks later. Comparable cultures of *Agrostis* without wheat were also grown. The main object was to test whether the interaction of weed competition and nitrogen supply on wheat can be explained wholly in terms of change in nitrogen uptake by the wheat, but this is not yet possible because the nitrogen analyses are unfinished.

The yield results suggest that *Agrostis* appropriated a greater proportion of nitrogen applied late to a mixed culture than nitrogen applied early, and so depleted the nitrogen supply to wheat more. In support of this, late nitrogen increased growth of *Agrostis* rhizomes more, though not shoots, than early nitrogen. Without *Agrostis*, the response in yield of wheat grain to nitrogen applied at sowing was about three times that of the later application; this effect of time of application was much greater than was found in the field at Woburn. In spite of this, the loss of wheat yield caused by competition with *Agrostis* was as great when nitrogen was given late as when given early, and the percentage loss was much greater with the late nitrogen application. Loss of yield from competition with *Agrostis* was greatly decreased by increase in early nitrogen application, as would be expected if *Agrostis* affected the wheat by depriving it of part of its nitrogen supply. On the other hand, the loss was independent of the rate of late nitrogen application, possibly

because any effect of additional nitrogen in making good depletion of the nitrogen supply by *Agrostis* was counteracted by increased growth and competition of the *Agrostis* rhizomes. (Witts.)

Physiological Effects of Virus Infection

Effect of infection with yellow-net virus on sugar content of sugar-beet leaves

Analyses of sugar-beet leaves from experiments done in the Plant Pathology Department (p. 99 below) showed that infection with yellow-net virus decreased the content of both sucrose and reducing sugar per cent of dry matter, especially in leaves that had well-developed yellow-net symptoms. This effect is the opposite of that produced by infection with beet yellows virus. (French.)

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

There have been an unprecedented number of staff changes in the department. M. V. Tracey resigned to become Head of the Commonwealth Scientific and Industrial Research Organization Wheat Research Unit, Sydney, Australia, and the vacancy has been filled by Dr. G. N. Festenstein. D. Fairclough and W. E. Whitman resigned, and these vacancies were filled by R. J. Stephens and Dr. W. A. Vincent. Margaret Holden returned from secondment to the West African Cocoa Research Institute (Tafo, Ghana) and R. H. Kenten has gone to take her place. As a result of a grant of $75,000 from the Rockefeller Foundation, to be spent during five years, two new positions have been created for work on the large-scale production of leaf protein. One has been filled by J. E. Morrison, and the other will be filled in the New Year.

The fourth International Congress of Biochemistry was attended by W. S. Pierpoint and N. W. Pirie; the latter, on the invitation of the Prime Minister, visited Ghana to consider the possibilities of making and using leaf protein there.

Blackening of potatoes after boiling

Samples of Majestic potatoes were taken from the Rothamsted and Woburn six-course rotation and dung NPK experiments during the 1957 harvest. Fertilizer treatments in the six-course rotation experiments consisted of basal PK, NK or NP with and without four levels of N, P or K respectively. In the dung NPK experiments farmyard manure was applied at three levels in all combinations with N, P and K. In both experiments the N, P and K were applied as ammonium sulphate, superphosphate and potassium choride.

Boiling tests were made before and after 5 months' storage. Potatoes from the Woburn DNPK experiment, irrespective of fertilizer treatment, blackened only slightly. In general, those from the other three experiments showed a much more marked blackening The only clear effect of fertilizer treatment was in the Rothamsted dung NPK experiment, where the potatoes from the plots receiving NPK together with farmyard manure at the highest level blackened little more than those from the Woburn DNPK experiment.

It is now generally believed that the pigment causing the blackening of potatoes after boiling is a complex of ferric iron and dihydroxy phenols. It is suggested that when potatoes are boiled, ferrous iron is liberated and combines with the dihydroxy phenols of the potatoes to give relatively colourless ferrous complexes, which oxidize in air to the intensely coloured ferric complexes. On this hypothesis the intensity of the blackening depends not only on the concentrations of ferrous iron and of dihydroxy phenols but also on those of other compounds present forming relatively colourless iron complexes.

Citric acid may be of major importance, since its concentration in potato tubers is high compared to that of the dihydroxy phenols.

Observations made here are in agreement with this hypothesis. Blackening was prevented by adding citrate, pyrophosphate or ethylenediamine tetra-acetate, which form relatively colourless complexes with iron, to the water in which the potatoes were boiled, and the colour of potatoes previously blackened by boiling was discharged by treatment with these reagents. Raw potatoes gave no immediate test for ferrous iron with *o*-phenanthroline, but potatoes tested immediately after boiling gave a strongly positive reaction and did not blacken after treatment with the reagent. The formation of ferrous iron on boiling was not confined to the stem end of the potatoes where the characteristic blackening occurs, and also occurred in samples of King Edward potatoes, though these did not blacken after boiling. Blackening of Majestic potatoes was intensified by adding ferrous sulphate to the water in which the potatoes were boiled, while similar treatment of King Edward potatoes caused only a slight yellowing.

Estimations were made of the iron, dihydroxy phenol and citric acid content of the potatoes. In addition, attempts were made to trap and estimate the ferrous iron formed during boiling. While the latter estimation was not put on a satisfactory quantitative basis, the results suggested that much of the total iron was liberated in the ferrous form on boiling. No differences were found in the dihydroxy phenol and iron contents of the Majestic potatoes to account for the observed differences in blackening. In 31 of a total of 33 estimations the stem ends of the potatoes were found to contain more iron than the rose ends. The value (μg. Fe/g. wet wt.) were 4·2–8·7 at the stem end (average 6·3), and 2·6–6·8 at the rose end (average 5·0). The results of the citric acid estimations suggested an inverse relationship between the concentration of citric acid and the intensity of blackening. The concentration of citric acid in the Woburn DNPK potatoes, which blackened only slightly, was generally much greater than that in the potatoes from the other three experiments. As found by other workers, the stem ends of the potatoes, at which blackening typically occurs, always contained much less citric acid than the rose ends. Thus in the Woburn DNPK experiment, the values (mg./g. wet wt.) ranged from 2·8 to 4·7 at the stem end and from 5·8 to 8·3 at the rose end. In the Rothamsted and Woburn six-course rotation experiments the comparable values were 0·8–2·0 (stem) and 3·2–5·1 (rose). In these three experiments no effect of the fertilizer treatments on the citric acid contents was found. In the Rothamsted DNPK experiment the citric acid concentration varied with the fertilizer treatment. The lowest values of 1·1 (stem) and 3·4 (rose) were obtained with the potatoes from the unfertilized plots. The highest values of 3·7 (stem) and 6·5 (rose) were obtained with the potatoes receiving NPK together with the highest level of farmyard manure. These results suggested that the observed differences in the intensity of blackening were due to differences in citric acid content. But in the Rothamsted DNPK experiment many of the other fertilizer treatments caused increases in the citric acid content without decreasing the blackening. This suggested that some other factor was involved, though, at least in part, the

lack of correlation may have been due to the very variable results of the boiling tests on different samples of the same batch of potatoes. (Mann.)

Plant leaf mitochondria

The medium described last year, containing sucrose, tris buffer, EDTA and citrate, is still the most effective one for the preparation of leaf mitochondria. This year's work has therefore been mainly concerned with its use in the preparation of mitochondria from tobacco.

Citrate, more than any other of the constituents of this medium, has a protective action on the oxidative properties of mitochondria of both tobacco and lupin leaves. The mechanism of this action is not well understood; but the ability of succinate to replace citrate suggests that it is a substrate stabilization of enzymes of the tricarboxylic acid cycle. There is apparently too little citrate in tobacco leaves to exert this protection when the leaves are disrupted. It is generally less than $\frac{1}{5}$ of that added in the extraction medium.

Further evidence has accumulated suggesting that the oxidative reactions of these preparations are components of a tricarboxylic acid cycle similar to that of animal mitochondria. Thus, many of them are inhibited strongly by cyanide, and reversibly by malonate. Also the products of oxidation, identified by paper chromatography, are other substrates of the cycle. Orthophoshate disappears during the oxidation of succinic acid, suggesting that this oxidation at least is connected to the synthesis of " energy-rich " organic phosphates.

The activity of the mitochondria varies with the physiological state of the leaves they are derived from. Thus preparations from the smaller younger leaves of a plant are more active, on a protein N basis, than those of the older leaves. The leaves of 3- and 4-month-old plants which are sending up flower shoots tend to be covered with a sticky exudate, and preparations made from such plants have little activity unless only very small leaves are used. It would be premature, however, to conclude that these activities represent the activities of the mitochondria *in vivo* until more is known about the factors present in disrupted leaves which affect the mitochondria during their isolation. (Pierpoint.)

Chlorophyllase

A study of the enzymic breakdown of chlorophyll in plant tissues has been started. At present remarkably little is known of the processes involved, although chlorophyll disappearance is such a marked feature of ageing in the normal leaf, and of changes associated with virus infections and nutrient deficiencies. Chlorophyllase, the enzyme catalysing the removal of the phytol group from chlorophyll (a comparatively small alteration in the molecule), has been investigated in the leaves of a number of species. Spinach-beet leaves are a particularly good source of the enzyme. So far it has not been possible to make a soluble enzyme preparation, and either acetone powders of fresh leaves or powders (containing chlorophyll) from leaves dried at 40° have been used. It has been confirmed that a high concentration of alcohol, acetone or ether is necessary for enzyme action to take place. Attention has

been directed to developing a rapid method for measuring enzyme activity, since most of the methods used so far are laborious. A number of surface-active agents had no influence on the rate of enzyme action when tested with either a high or low concentration of acetone present. The enzyme is said to be active in an aqueous system at about 65°, but this has not been satisfactorily confirmed because the substrate was affected at this temperature. The separation by paper chromatography of the breakdown products of chlorophyll is now being studied. (Holden.)

Properties of fragments of tobacco mosaic virus (TMV)

This section of last year's report dealt mainly with the effects of ribonuclease, or extracts whose activity could plausibly be attributed to ribonuclease, on the infectivity of TMV fragments made by treatment with phenol. These experiments have continued, but, in an attempt to get evidence about the widely held view that nucleic acid is solely responsible for the infectivity, most attention has been given to systems in which it would be unreasonable to attribute the inactivation to ribonuclease. The problem has to be posed in this roundabout way because the disinfection of TMV fragments is the most sensitive test for ribonuclease that we know, and the preparations of TMV that we use are not themselves always free from ribonuclease.

Infectivity is destroyed by various oxidizing systems that would not be expected to affect the structure of a nucleic acid built up in the conventional way. Mitochondria made from young tobacco leaves, especially in the presence of ethylenediamine tetra-acetate or some of the Krebs cycle substrates, bring about inactivation. It may be that this is a consequence of oxidizing reactions or of enhancement of ribonuclease activity, but a definite decision on these points has not yet been possible. Neither mechanism offers a plausible explanation of the more rapid loss of infectivity in the complete absence of air or of its loss in the presence of thiamine and thiaminase made from bracken fronds. The latter is a particularly interesting phenomenon, because it may shed light on the function of this curious enzyme; one possibility is that, *in vivo*, it is concerned with the attachment and detachment of groups along the side of a nucleic acid chain.

Studies on the infectivity of TMV fragments have an intrinsic interest, but they may also shed light on the first stages in the normal processes of infection. There is already good evidence that the inoculum is dismantled when it enters a susceptible cell. This has been strengthened by measurements of the distribution of radio-active P in different fractions of the leaf at intervals after inoculation with TMV containing radio-active P. After 3 days more than half of the labelled P appears in low-molecular-weight forms. This is clear evidence for the dismantling of the inoculum, but so far all attempts to get a similar dismantling with a leaf preparation, *in vitro*, have failed. (Pirie in collaboration with Bawden.)

Large-scale production of leaf protein

This work has a two-fold object; to develop techniques for using plants or parts of plants that do not at present contribute to human

nourishment, and to increase the amount of food that can be got with existing crops from a given area in a given time. We have not yet tackled the problems of selection and husbandry that the first object involves, but, now that the general principles of extraction are becoming stabilized, we have made some progress with the second.

Winter wheat and rye were drilled more closely and fertilized more heavily than in normal farm practice; they are useful crops because they permit work to start at the beginning of May, but the yield of extracted protein (256 and 360 lb./acre respectively) is not as high as that given by spring-sown oats cut in June (471 lb./acre). A second, June, cut from the winter-sown wheat produced half as much protein as the first cut. The dry spring and wet, sunless summer showed that we have still a lot to learn about the management of these heavy, leafy crops. The cereals are convenient, but it is probable that they are far from ideal. Thus, nettles growing more or less wild except for some fertilization, gave 546 lb. of extracted protein per acre, which compares favourably with the sugar-beet figures quoted last year.

In comparing these yield figures with those got by normal methods of agriculture, three points should be borne in mind. With cereals the land is ready for ploughing and re-sowing by the middle of June, the protein that we do not extract is still left in the discarded fibre and available for cattle feeding, and we have only just begun studying the conditions for efficient husbandry.

Only one new crop has been added to our list of protein sources during the year—river weeds. These could be important because 100 miles of river is cleared of weeds each year by just one of the local Drainage Boards, and the product is left to rot in heaps on the bank. We were able to extract 47 per cent of the protein from a rather mature batch.

The standard product was again the 5-lb. block containing 50 per cent water which needed to be deep frozen; but work has continued on other methods of preservation. As extracted, the protein contains a large proportion of lipid, which is readily made rancid by the bacterial flora developed during the extraction process. Solvent extraction, air drying, vacuum and freeze drying, and drying after admixture with various flours and meals have been tried and have been found to be generally successful in preventing this deterioration. It has been necessary to preserve wet samples of protein for dispatch overseas, and where refrigeration was not possible some form of canning was essential. Work has been carried out on direct sterilization by canning, the difficulties found being mainly due to the low rate of heat penetration and the consequent vigorous heat treatment required for a sterile pack. This destroys some of the palatability of the protein, particularly in the outside layers. Work is now being concentrated on the production of a " commercially sterile " pack which can be rendered inert by the bacteriostatic action of salt or antibiotics, on the principle that these agents can easily be removed on opening the packs by washing the insoluble protein with water.

We have not improved on ravioli and cromeskis, described last year, as vehicles for presenting the protein to possible consumers in

Britain, but several standard Ghanaian dishes have been supplemented with leaf protein and proved acceptable there. More animal feeding experiments have been completed, and some are running at present; they confirm that the protein has a feeding value similar to that of high-grade fish meal. (Byers, Morrison, Pirie, Stephens and Vincent.)

The potato-root eelworm hatching factor

The Nematology Department supplied a record quantity of potato-root diffusate (4¼ tons) during the past season. The bulk of this material has been treated with charcoal under the conditions mentioned in *Rep. Rothamst. exp. Sta. for 1956* (p. 93, Wiltshire), and the active material recovered by elution of the charcoal. The recoveries obtained in the past season have been lower (32 per cent average of 57 experiments), than those obtained by Wiltshire in the 1955 season (39 per cent average of 8 experiments). As noted by Wiltshire, the recovery of activity fluctuates widely, and the causes of this are being investigated. One variable factor which may be involved is the inorganic ion content of the solutions assayed.

Each batch of crude material, obtained by evaporation of the charcoal eluates, has been purified by a three-stage chemical procedure elaborated during the past year. This procedure has given consistent and reproducible results, an average of 85 per cent of the activity in the charcoal eluates being obtained in 9 per cent of the weight. The material obtained is a mixture of organic acids. Chromatographic procedures have been used to resolve this mixture into a number of fractions which are being tested for hatching activity.

The behaviour of the hatching factor on paper chromatograms has been investigated. Six solvent systems have been used, and the R_F values associated with the hatching activity determined in each case. In all the solvent systems used, hatching activity is associated with an elongated fluorescent spot on the chromatogram, but at least some of this fluorescence is due to inactive material. The R_F value of the hatching factor, in one of the solvent systems, phenol–water, is the same as that reported for the hatching factor present in the tomato-root diffusate. The hatching factor is not inactivated by periodate, nor by the digestive juices of *Helix pomatia*, suggesting that a glycosidic moiety is not an essential feature of the active molecule. (Clarke.)

Plant enzyme reactions leading to the formation of heterocyclic compounds

The work on the blackening of potatoes after boiling and on the potato-root eelworm hatching factor has seriously curtailed further study of plant enzyme reactions leading to the formation of heterocyclic compounds, and on the role of plant amine oxidase in the formation of pyrrolidine and piperidine alkaloids. (Clarke and Mann.)

PLANT PATHOLOGY DEPARTMENT

P. H. Gregory

F. C. Bawden was chosen as director when Sir William Ogg retired in September 1958. The staff of this department, which he joined in 1936 and of which he has been head since 1940, are delighted that this leadership is now extended to the whole of Rothamsted. P. H. Gregory was appointed head of the department from 1 October 1958. L. Broadbent left to take up a post at the Glasshouse Crops Research Institute, Littlehampton. G. Salt was seconded for two years as plant pathologist to the Sudan Government Service.

F. C. Bawden, L. Broadbent, E. W. Buxton and J. M. Hirst all spoke by invitation at the Golden Jubilee Meeting of the American Phytopathological Society at Bloomington, Indiana, in August, and E. W. Buxton attended a Conference at Purdue University on Panama Wilt of Bananas. J. M. Hirst was awarded a Kellogg Fellowship and spent three and a half months visiting research stations and universities in Canada and the U.S.A. F. C. Bawden also attended meetings of the Advisory Committee on Agricultural Research in the Sudan at Khartoum in January and of the Technical Co-ordinating Committee for Agricultural and Allied Research in the West Indies in June.

A. Kleczkowski and B. D. Harrison attended the International Congress for Microbiology at Stockholm in August 1958.

D. Perry was awarded the Ph.D. degree of London University and Alison Fletcher the B.Sc. degree.

Viruses and Virus Diseases

Little is known about what takes place during the first few minutes and hours after a plant is inoculated with a virus. In studying the early events of infection with tobacco mosaic virus in tobacco and *Nicotiana glutinosa* plants, inocula of the whole virus and of the infectious ribonucleic acid obtained from the virus were compared. By infectivity tests new virus was detected about 2 hours earlier in plants inoculated with the nucleic acid than in plants inoculated with the whole virus. Six hours from inoculation with nucleic acid was the shortest period when newly formed virus could be detected. A similar time difference was found when *N. glutinosa* plants inoculated with the two kinds of inocula were dipped in hot water at 50° C. for 30 seconds. This treatment reduced the number of local lesions from either kind of inoculum when it was applied immediately after inoculation, but when it was delayed for 4 hours with the nucleic acid and 6 hours with the whole virus it no longer had any effect.

Nicotiana glutinosa plants inoculated with the nucleic acid produced very few lesions when placed at 37° C. immediately after

inoculation but the usual numbers when the treatment was delayed for about 2 hours. Exposure to 37° C. does not affect the number of lesions produced by plants inoculated with whole virus, and 2 hours may be the minimal time for new virus to be synthesized when nucleic acid is the inoculum. (B. Kassanis.)

Further studies of the decomposition products of tobacco mosaic virus gave evidence that the nucleic acid does not contribute to the surface potential of the virus particle. The fact that the electrophoretic mobility of tobacco mosaic virus is greater than that of the non-aggregated virus protein (obtained by splitting the virus by alkali) seems to result from the way the electric charges are distributed on the surface of the non-aggregated protein particles and from the way these particles are combined either in the native virus or in artificial aggregates of the protein particles. The lack of contribution of nucleic acid to the surface-charge density of the virus particle agrees with the X-ray studies of radial density distribution by Caspar (1956) and Franklin (1956), who showed that the nucleic acid is positioned near the central axis of the virus particle.

Alkali-produced disaggregated protein of tobacco mosaic virus is an antigenically heterogeneous mixture and lacks an antigenic group present in the original virus particle. Recombination of the proteins with nucleic acid seems to restore the lost antigenic group, although the nucleic acid by itself is not antigenic. The recombined nucleoprotein behaves as an antigenically homogeneous material. This is so probably because of aggregation of the protein recombined with the nucleic acid. Aggregation caused by lowering the pH to about 6·5 also leads to the loss of antigenic heterogeneity, although it does not restore the lost antigenic group. (A. Kleczkowski.)

Electron microscopy

Some success was obtained in finding methods for mounting plant viruses for electron microscopy at high resolution. The technique of heavy metal staining was successfully applied to particles of a strain of tobacco rattle virus. In normal shadowcast mounts the particles are rods about 21 mμ wide, with a central hole which can be seen when short particles appear " end on ". When mounted on thin carbon films after staining with uranyl acetate, lanthanum nitrate or thorium nitrate, the particles show a dense central thread, about 4 mμ wide, surrounded by an unstained and apparently structureless region. After staining with phosphotungstic acid the central dense region appears about 6 mμ wide, sometimes very densely stained but sometimes appearing as a less-dense region with very heavily stained edges, as though the material which filled it had been partly extracted. When the particles are treated with phosphomolybdic acid, or with uranyl acetate after incubation with trypsin, a regular cross banding with a spacing of about 2·5 mμ becomes visible in the outer region away from the central thread. This is the first time that a structure of this order of size has been seen in a plant virus with the electron microscope, and it may well represent the pitch of a helical protein structure, if, as seems likely, tobacco rattle virus has an internal structure broadly similar to that of tobacco mosaic virus. Attempts are now being

made to characterize the two parts of the particles as revealed by these staining techniques.

Epoxy resins ("Araldite") show promise as a medium for embedding plant material before sectioning for electron microscopy. The blocks are less easy to cut than the usual methacrylate mixture, and unlike methacrylate it does not evaporate in the electron beam, so that for a given image contrast the sections must be thinner. These disadvantages are more than offset by the absence of characteristic artefacts produced by methacrylate shrinking during polymerization. When centrifuge pellets of tobacco mosaic virus are embedded and sectioned the virus rods are recognizable in sections thin enough for adequate electron microscopy without removing the embedding resin by solution and then shadowing, a technique liable to introduce gross artefacts. This difficulty could be partly avoided if it were possible to use readily stained virus particles, and this is one reason why time has been spent in a study of possible staining methods rather than on sectioning.

The number of routine examinations made for other members of the department continues to grow. In the past these have usually been of virus particles in clarified sap, and the mounts have required only the minimum of time for their preparation and examination. There is now a tendency for workers to require more highly purified material, and the electron microscopist necessarily has to report on the state of the specimen in at least the final stages of purification. Among work done for other departments progress has been made in finding the conditions which must be met for satisfactory high-resolution electron microscopy of minerals of the montmorillonite group, some of which have so far proved extremely difficult to study in this way (see report of Pedology Department). The problems are somewhat similar to those found in making good preparations of viruses. (Nixon.)

Soil-borne Viruses

Mechanism of soil transmission. Strong evidence was obtained that soil-inhabiting organisms are concerned in the soil transmission of certain viruses of the ringspot type. Detailed studies were therefore made on the fauna of soils taken from the parts of raspberry plantations where raspberry ringspot virus occurred, and of soils from adjacent virus-free areas. The arthropod populations were analysed by F. Raw, Entomology Department, and the nematode populations by R. D. Winslow, Nematology Department. The virus-containing soils possessed more Collembola and certain types of Acarina, and they sometimes contained more of certain plant-parasitic nematodes than did the virus-free soils. Evidently the composition of the soil fauna in virus-containing and virus-free soils differs in many respects, but the relevance of these differences to the occurrence of the virus is uncertain. (See also reports of Entomology and Nematology Departments.)

Purification and properties of tobacco rattle virus. Purified preparations of a strain of tobacco rattle virus, originally obtained from Scotland, contained rod-shaped particles of the same width but whose lengths fell predominantly into two categories. The two types of particles were separated by high-speed centrifugation in a

sucrose density-gradient. Both types seemed to be nucleoproteins of the same or similar constitution, but only the longer particles were infective. (Harrison.)

Arthropod-transmitted Viruses

Sugar-beet viruses

The aphid-transmitted yellow-net virus of sugar beet (*Rep. Rothamst. exp. Sta. for 1951*, p. 164) has been studied in pot culture (in collaboration with S. A. W. French of the Botany Department) to determine the effect of spraying with gibberellic acid on susceptibility and symptom production, and the effect of virus on yield and symptom production, the effect of virus on yield and on concentration of carbohydrate in the leaves. The loss in yield caused by yellow-net virus in plants 2 months old was smaller than would be expected for plants similarly infected with necrotic beet yellows virus. Plants treated with gibberellic acid lost about 30 per cent of their root yield as a result of infection, and the untreated ones lost about 20 per cent. The effect of gibberellic acid (applied once during the first month of growth) was a temporary *increase* in yield of tops. Later there was a decrease in yields of laminae, while petioles and roots were not affected.

Plants infected by yellow-net virus, especially middle-aged leaves that show the main yellow-net symptoms, had much less sucrose and reducing sugars than normal plants. The yield of sugars per 1,000 gm. fresh weight of leaf laminae averaged about 3·5 gm. for healthy plants, but only 0·4 gm. for middle-aged leaves of infected plants and 1·5 gm. for other leaves. Yellow-net virus thus contrasts strongly with beet yellows virus which increases the carbohydrate concentration in infected leaves, sometimes to ten or more times normal. (Watson and Chessin.)

Cereal viruses

The host range of cereal yellow dwarf among meadow and hedgerow grasses was investigated by using large numbers of the vector, *Rhopalosiphum padi*, to ensure that the virus was introduced in sufficient quantity. *Festuca pratensis, F. rubra, F. elatior, Poa trivialis, P. pratensis, Dactylis glomerata, Anthoxanthum odoratum* and *Agrostis tenuis* became infected but behaved as symptomless carriers. *Avena fatua, Bromus sterilis, B. arvensis,* and also maize and rice, showed symptoms of leaf discoloration and stunting. *Agropyron repens* and *Arrhenatherum elatior* appeared to be immune. (Mulligan.)

Two yellow dwarf viruses of cereals have now been compared in both glasshouse and in field experiments. They are considered distinct viruses rather than strains of one virus, because plants infected with the avirulent virus become infected with the virulent virus just as severely as healthy plants, and the virus derived from these plants after a few weeks' growth gives virulent symptoms when subinoculated to healthy plants. The avirulent strain does not protect a plant from the virulent infection, and the only evidence of interference seems to be that the avirulent virus is eliminated by the virulent one. (Watson, Govier and Mulligan.)

In field plots infected with the two viruses at fortnightly intervals between April and June the earliest infection caused loss of 80 per cent of the yield of Blenda oats and about 65 per cent of that of Koga II wheat and Proctor barley. The second and third infections caused losses of about 50 per cent and 15 per cent respectively. With the avirulent virus the loss from the first two infections was 40–50 per cent and the last negligible. Oats were again the most severely affected. (Watson and Mulligan.)

Ryegrass mosaic. Ryegrass mosaic virus was transmitted by *Abacarus hystrix* (Nal.) to ten out of twenty S22 Italian ryegrass test plants when each was tested with ten mites immediately after feeding for 3 days on infected ryegrass leaves. Such mites lost half their infectivity in about 3 hours while feeding on Capelle wheat and almost all infectivity after 12 hours. Healthy mites fed on infected leaves for 12 hours transmitted as readily as those fed for 24 hours or 48 hours, but those fed for only 6 hours did not transmit. Freshly extracted sap of infected S22 Italian ryegrass plants at pH 7 lost most of its infectivity in 10 minutes at 55° C. At room temperature half the infectivity was lost in about 3 hours and most in 24 hours. In addition to species mentioned in last year's report the following developed streaking when infected: *Alopecurus agrestis, Avena fatua, Avena sativa, Dactylis glomerata* and *Oryza sativa*. The streaking in Blenda oats becomes rusty in the upper leaves, and a naturally infected plant has been identified from the field. The streaking in cock's foot S143, S37 and S26 resembles that caused by cock's-foot streak virus, and the ability of *Myzus persicae* to transmit ryegrass mosaic is being tested. Cock's-foot streak virus transmitted by *M. persicae* to cock's foot has been transmitted by sap into S22 Italian ryegrass, in which it gives symptoms like ryegrass mosaic. Rod-shaped particles like those of ryegrass mosaic (*Rotham. exp. Sta. Rep. for 1957*) were found in two out of five samples examined by the electron microscope. (Mulligan.)

Wheat striate mosaic. The three races of hoppers isolated last year were used to find out the relation of virus inheritance to the vector-efficiency of the parental strain of hopper and the time of parental virus acquisition.

Efficient races transmitted to a high proportion of the nymphs, but inefficient races to very few. Nymphs from females of efficient races frequently transmitted on the day of hatching, so if the virus multiplies in the tissues of the inheriting nymphs it presumably does so in the egg during the development of the embryo. This view is strengthened because many infected embryos die before hatching. For this reason the progeny of infective females from efficient races are fewer than those of non-infective mothers or mothers from inefficient races (nymphs did not inherit virus unless their mothers or grandmothers had fed on infected plants). Because infective races of hoppers reproduce more slowly than non-infective ones, there is a population pressure to eliminate infective individual lines from mixed cultures, with a result that most become healthy when maintained in conditions where they cannot become infective by feeding on infected plants. (Watson and Sinha.)

Non-persistent viruses

It was reported last year that the non-aphid-transmissible potato virus C (from Edgecote Purple potatoes) can readily be transmitted by *M. persicae* if it is first inoculated to *N. glutinosa* in combination with potato virus Y. Viruses transmitted by aphids from such mixed infections in *N. glutinosa* frequently give black, necrotic local lesions, characteristic of potato virus C when inoculated to Majestic potatoes, but potato virus Y alone has never given such lesions, and neither have isolations from it. Combined viruses that gave local lesions followed by necrotic systemic infection in Majestic potatoes retained their character in *Nicotiana glutinosa*. Some have been maintained by sap inoculation through *N. glutinosa* and single-lesion isolates from Majestic potatoes for 18 months. Although such combined viruses may be changed by systemic passage through Majestic potatoes (as was the original aphid-transmitted potato virus C), their behaviour suggests that they may be " hybrids ".

Attempts to transmit either potato virus C or tobacco mosaic virus as contaminants of henbane mosaic virus have failed. So also have attempts to transmit the non-aphid transmissible strain of cucumber virus 1 as a contaminant of yellow cucumber virus 1.

A virus occurring naturally in Jersey and sent by Mr. D. E. Richardson of the National Institute of Agricultural Botany was very like the aphid-transmissible C virus mutant, except that its aphid-transmissibility did not disappear after passage through Majestic potatoes; also an isolate from it caused necrotic systemic lesions in Majestic potatoes resembling those caused by isolations from mixtures of potato viruses C and Y. (Watson.)

Tobacco mosaic. Attempts to transmit tobacco mosaic by using *M. persicae* whose stylets had been exposed and coated with tobacco mosaic nucleic acid before feeding on healthy seedlings were unsuccessful. Ribo-nuclease was applied to the exposed stylets of *M. persicae* before feeding on plants infected with henbane mosaic, and also after feeding. Both treatments reduced the probability of subsequent infection, but similar treatments with distilled water did so also. (Watson and Delobbe.)

A virus disease of carrots. An aphid-transmitted persistent virus was isolated from yellow, stunted carrot plants at Kennett, Cambs. The symptoms resembled those described by L. Stubbs from Victoria, Australia, as " carrot mottley dwarf virus ". The vector is the carrot aphid (*Cavariella aegopodeae*), and the virus is not sap-transmissible. (Watson.)

Potato virus diseases

Aphids were exceptionally numerous on potato crops in May and June 1957, but numbers then declined rapidly, and there was no summer migration during July and early August. The effect of these infestations on spread of viruses in the field was revealed during 1958 on plants grown from seed tubers saved from experimental plots of the previous year. An experiment on aphid control, done with P. E. Burt of the Insecticides Department, showed that spraying with DDT and " Metasystox " on 3 June 1957 reduced the

spread of leaf roll to less than a quarter of the amount on unsprayed plots, but that sprays applied on 19 June, 3 July or 30 July had no significant effect. Spread of rugose mosaic was not reduced by any of the four applications. Thus, although the plants were infested with aphids before any spray could be applied, the first spray applied when about 80 per cent of the plants had emerged almost stopped the spread of leaf-roll virus within the plots. The lack of effect from later sprays in 1957 supports previous evidence that the early sprays are the most important, and that the spread of virus Y is attributable to the great activity of winged *Myzus persicae* while the plants are emerging. (Broadbent and Heathcote.)

Insecticide trials on potatoes in co-operation with the National Agricultural Advisory Service were continued in 1958, when most ended. Despite the spread of virus in 1957 in many parts of Britain, few of the sprayed stocks that had been kept for several years deteriorated badly, and the recommendations to farmers to keep their sprayed stocks for 3, 4 or 5 years have been justified. The high cost of certified potato-seed tubers has stimulated interest in our work, and some growers are endeavouring to keep their stocks longer. (Broadbent and Heathcote.)

To obtain further information on the relative ability of winged and wingless aphids to transmit potato leaf roll and rugose mosaic (virus Y) an experiment was done in 1957 in collaboration with P. E. Burt of the Insecticides Department on small plots applying " Phosdrin ", a systemic insecticide that remains active for only 2 days, at intervals to prevent wingless aphids becoming numerous but to leave the plants open to visits of winged aphids during most of the season. One set of plots contained no virus-infected plants, and the other had one plant with leaf roll and one with rugose mosaic in each half plot. Haulms were removed at different dates: 15 July, 19 August or when dead. " Phosdrin " was first applied on 6 June 1957, 2 weeks after the first plant emerged. The percentage of plants infected in the central rows of these plots were:

	+ " Phosdrin "		— " Phosdrin "	
	LR	RM	LR	RM
No infectors	2·5	61·2	12·5	56·2
Autumn harvested	10·0	87·5	37·5	97·4
Mid-season harvested ...	8·1	94·7	30·0	92·5
Early harvested	10·0	77·5	34·2	59·0

As in the other Rothamsted experiments, most of the spread occurred early. Aptera apparently played little or no part in spreading virus Y (RM). If the incidence of LR in the plots treated with " Phosdrin " represents that spread by alatae, there must have been considerable spread of LR virus by aptera before mid-July.

During the extremely wet season of 1958 aphids in general and *Myzus persicae* in particular were many fewer than in 1957.

Eleven sticky cylindrical aphid traps were operated in unsprayed potato crops near to sprayed ones in different parts of England. *M. persicae* were few during May and June, but became numerous in the Wash area during July. Elsewhere they remained few throughout the summer. (Broadbent and Heathcote.)

Fungi and Fungus Diseases

Potato blight

Phytophthora infestans attacked potato crops unusually early in 1958. It was first found on commercial crops on 16 July, following a 19-day period when conditions within crops continuously satisfied the Beaumont criteria. The fungus spread rapidly in persistently wet weather, and unsprayed Majestic crops were almost destroyed at the end of August. Majestic crops sprayed twice with copper oxychloride yielded only 1 ton/acre more than unsprayed plots. The first spray applied in mid-July delayed the epidemic considerably, but later sprays did little good, presumably because the residues were too rapidly removed by rain.

In continued observations on the early stages of blight epidemics 700 King Edward and 140 Up to Date tubers naturally blighted in 1957 were planted among a similar number of healthy Majestic tubers. The first above-ground symptoms were discovered on 18 June on one of seven King Edward plants whose stems were invaded by the fungus growing from the seed tubers. The first local lesions on foliage were found on 27 June, and almost all the plants in the plot had become infected by 29 July. This series of experiments, in which only diseased tubers with live sprouts have been planted, cannot be used to assess the importance of naturally infected ground-keepers as sources of blight. To simulate these we planted 300 naturally infected tubers at each of two depths in November 1957. The winter was comparatively mild, and by July 1958, 37 per cent of those placed 4 inches deep had produced plants compared with 30 per cent of those at 8 inches, but on only one plant (King Edward, at 4 inches) were stems above ground invaded by the fungus.

Last year we reported the occurrence, in an irrigated plot, of foci of infected plants which we were unable to associate with any nearby invaded stem. It seemed possible that the fungus, introduced in diseased tubers, might be able to start epidemics without invading any shoots. To test this we planted a plot in which over 600 healthy Majestic tubers, 24 inches apart, alternated with Pentland Ace tubers. The Pentland Ace tubers were artificially infected with Race 3,4 of *P. infestans*, and all the eyes were removed to prevent growth. As in 1957, the plot was irrigated to make good any deficit of rain below 1 inch/week. Little irrigation was required in June because 4½ inches of rain fell, a third of it during 2 days at the end of the month caused water to stand in the furrows. Six days later, on 4 July, blight lesions were found on 27 Majestic plants, all on the lowest leaves which were hanging over the furrows. Isolates from each of 25 lesions found on 4 July were tested on Pentland Ace foliage (which is attacked by Race 3,4 but not by the common Race 4) and 80 per cent caused infections. By contrast, none of 30 isolates from King Edward foliage in the adjoining experiment, mentioned above, infected Pentland Ace. At this early stage of the epidemic, there would have been little spread of the fungus between experiments. The high rate of recovery of Race 3,4 from the plot containing " blind " Pentland Ace tubers suggests that, under wet conditions, attacks of blight can be started, without

the invasion of stems, by *P. infestans* introduced into unsterile soil on an appreciable food base. (Hirst and Stedman.)

Experiments had shown unexpectedly little difference in the dates at which the varieties Up to Date, King Edward, Majestic and Arran Viking became defoliated by blight. Experiments were continued in 1958 using a 4 × 4 Latin square in which the plots were surrounded by a non-susceptible guard. As non-susceptible guards to reduce possible spread from plot to plot, which was suspected in previous years, kale was planted between the columns of the potato plots and mangolds between the plots within columns. On 18 July blight was found in one King Edward plot, and all plots were then infected artificially so that the difference in the time of arrival of natural blight in plots found in 1957 could be avoided. The epidemic was particularly rapid and severe. Once again only small differences in the rate of destruction of varieties were recorded. In Arran Viking 50 per cent defoliation was reached 4 days later than Up to Date and King Edward and 2 days later than Majestic. Other varieties showing more resistance are to be included in future trials.

When leaves were marked to assess the progress of blight, defoliation resulted mainly from the direct infection of leaflets and not from their indirect destruction through stem or petiole lesions. Indirect destruction was more frequent in 1957, and the effect in 1958 can probably be explained by the prolonged periods of weather favourable for spread of the fungus. Lesions appeared every day and many marked leaflets became " peppered " with lesions and were destroyed before infection of stem and petiole could have an effect.

When leaf axils of glasshouse plants were inoculated with a droplet of spore suspension, the varietal differences in susceptibility of stem and petiole observed in 1957 were confirmed. In the field, stem lesions were abundant in King Edward and Up to Date, fairly frequent in Majestic and few in Arran Viking, and as a result of the agreement between field and laboratory observations the test was extended to thirty-three varieties of all maturity groups. Varieties differed in susceptibility but further experiment is required to assess the reliability of such a test.

There is evidence that some varieties produce more spores than others. In Arran Viking in the field the width of the zone producing spores changes as the lesion grows. In the susceptible Up to Date the average width of the sporing zone was similar (3·2–3·9 mm.) irrespective of the size of the lesion. In Arran Viking the sporing zone of lesions 5 mm. diameter was only 1 mm. wide, but in large lesions it was almost as wide as in Up to Date. As a result, Arran Viking produced relatively few spores on the smaller lesions, a feature seen also in the laboratory in the resistant varieties Ackersegen and Ås. Although, with suitable temperature and humidity, the sporing zones of Arran Viking can be the same as a more susceptible variety, in a field crop these conditions may be reached only at the lowest level in the canopy.

Of thirty-two commercial varieties grown for observation in small field plots, Ackersegen, Ås and Ontario remained green longest, and gave reduced sporulation. In another experiment with

plots of the hypersensitive varieties Orion, Ulster Torch and Pentland Ace, only Orion showed some foliage and tuber resistance when inoculated with its specialized race. Ulster Torch gave the impression of being very susceptible because leaves of the middle and upper canopy abscissed readily when only partially infected, leaving stems green and bare. The fallen leaves remained green and spored profusely in the furrows, and at lifting 19 per cent of the tubers were blighted.

To investigate the effect of age on the susceptibility of potato foliage to blight, the variety Majestic was planted at fortnightly intervals from 30 April to 16 June. The last plot to be planted was 50 per cent defoliated only 9 days later than the first, and defoliation in plantings on other dates was intermediate between these two extremes.

In a field trial of chemicals for the destruction of potato haulm, plots 10 rows by 30 feet of Ulster Supreme in a 2 × 5 randomized block were sprayed when 75 per cent defoliated by blight. The rate of application was equivalent to 40 gal./acre of sulphuric acid 50 per cent B.O.V., sodium arsenite 1 gallon, sodium chlorate 24 lb. and FB2 2 lb./acre (FB2 is 1 : 1′-ethylene-2 : 2′-dipyridylium dibromide, supplied by Plant Protection Ltd.). Sulphuric acid killed both foliage and stems most rapidly. FB2 was a little faster than arsenite in the initial killing of leaves, but slower in killing the stems. Chlorate was slow killing both leaves and stems. All chemicals gave good control of weeds compared with the unsprayed plots. (Lapwood.)

Apple Scab

Tests of surface-wetness recorders designed to assist the accurate timing of curative sprays were continued in conjunction with the Meteorological Office and the Ministry of Agriculture.

Trapping of ascospores was continued in orchards at Wisbech and in Kent and Suffolk, but the results have not yet been analysed. We continued a series of measurements designed to test whether it is possible to forecast the number of ascospores to be expected during spring. The two methods being tested both rely on estimating the weight of dead leaf remaining in orchards shortly before bud-burst. In the first method the extent of this source would be related to tests of the ascospore productivity of leaf samples, of known area, in which the maturation of perithecia has been hastened artificially. Trials in 1958 suggest that this is feasible but that the number of ascospores liberated would be considerably less than from replicate samples left to mature naturally. The second method would also relate the amount of dead leaf in spring to ascospore productivity but indirectly through the regression of percentage of leaves infected in autumn on the subsequent ascospore productivity of samples of the same leaves the next spring.

Tests of ascospore productivity were made on uniform area samples of leaves formed on the extension growths of unsprayed Laxton's Superb in May, June, July or August 1957. The later formed leaves were most heavily infected and produced most ascospores, and the first leaves to fall in autumn produced fewer ascospores than those which fell late. (Hirst and Stedman.)

Fungi on hay

Work on the mycofloral succession on hay was started because mouldy hay is thought to have a role in the etiology of some human and animal diseases (e.g., " farmer's lung ", bovine mycotic abortion, aspergillosis in poultry), and also for its importance as an agricultural problem.

Preliminary studies on the difficult problems arising in sampling hay to assess mould content have involved: (1) shaking a weighed specimen of hay in air in a small wind tunnel to find what respirable spore and dust load was set free into the air; and (2) subsequently washing the samples to estimate the spore load entering the digestive tract of farm animals. The respirable and ingested fractions have been estimated by use of the Cascade impactor, haemocytometer counts and by dilution cultures.

The samples of normal hay examined contained little dust and relatively few fungus spores. The spores put into the air were typical of the dry air spora of this country (e.g., *Cladosporium*, *Helminthosporium*, *Alternaria*, *Botrytis*, *Polythrincium*, *Ustilago*) and support the view that the outdoor air spora is derived from above-ground vegetation rather than from the soil. Specimens of mouldy hay put very many spores into the air, classifiable by direct visual examination and in culture as predominantly species of *Aspergillus*, *Penicillium* and related moulds, *Monotospora lanuginosa*, *Absidia* and *Actinomycetes*. Many isolates were thermophilic, growing well at 40° C. The total numbers of spores removed from four samples varying from normal to increasingly mouldy hay were as follows in millions/gm. dry weight: in air—3, 5, 67, 342; in washing—48, 89, 306, 526.

The rate of spore removal from samples of mouldy hay shaken in the wind tunnel for an hour decreased rapidly. Cumulative percentage output was approximately linear when plotted against time on log. probability paper, and in a wind of 1 m./second (2·2 m.p.h.) 50 per cent of the spores were removed during the first 2 minutes.

In the samples examined there was no evidence that plant material had been broken down into dust by moulds. Almost all the dust in the size range 1–15 μ consisted of fungus and actinomycete spores. (Gregory.)

Air-borne spore trapping

Since 1956 we have been co-operating with the Meteorological Office in studying variations in spore concentration with height. Suitable apparatus has now been developed for collecting and examining catches. While it is too early for definite conclusions, it seems probable that the distribution of air borne spores with height is much affected by lapse-rate. A wide range of fungus spores and pollen grains have been caught, and at times in high concentration, for example, 53,000 *Cladosporium* conidia/cu. m. of air at 2,000 feet on the afternoon of 18 July 1957.

Part of the work, done in collaboration with workers at Bristol and Cardiff, has been to test whether attacks of *Puccinia graminis* can be attributed to uredospores dispersed over long distances.

Results from several years will be necessary in view of the few occasions and spores involved, but it is encouraging to have found single uredospores, indistinguishable from *P. graminis*, in four catches between 4,000 and 9,000 feet over the English Channel (30 miles south of Portland Bill) on 4 July 1957. These catches indicate a concentration of the order of 30 uredospores/cu. m. of air. (Hirst and Stedman.)

Eyespot (*Cercosporella herpotrichoides*), lodging and take-all, (*Ophiobolus graminis*), favoured by wet summer weather, were unusually severe in 1958. On Broadbalk the 1st, 2nd, 3rd, 4th and 7th consecutive wheat crops after 1 year fallow on plots 2B, 3 and 7 averaged: 23, 68, 79, 77 and 60 per cent straws infected by eyespot; 9, 40, 49, 43, and 30 per cent with severe eyespot lesions; 26, 35, 41, 36 and 18 per cent of their areas were lodged; 0·1 8·6, 5·5, 7·1 and 2·4 per cent straws had take-all on the roots. The lower incidence of eyespot and take-all on the 7th as compared with the 2nd, 3rd and 4th consecutive crops may indicate a decline in disease under continuous cropping, but was also associated with control of weeds by spray, which was applied only to this section. Take-all caused greying of straws and ears within the small areas on which the more severe " patch " form of the disease had been recorded for the first time on Broadbalk plots in 1957. The patch form did not recur on Broadbalk plots in 1958, but was found on a non-experimental part of the field in the second wheat crop after 2 years fallow. Loss in grain of about 40 per cent was associated with the greying, and of about 80 per cent with the severe patch form of the disease. (Glynne and Cox.)

Recent changes in the alternate wheat and fallow experiment showed the dramatic effects of: (1) substituting a wheat crop for fallow; and (2) thin seeding. Sown at 3 bushels/acre, the first wheat crop after fallow had only a trace of take-all, the second was very severely stunted by the disease; but when sown at $\frac{1}{3}$ bushel/acre the second wheat crop was lightly, and the third severely infected. Eyespot was severe after a 1-year fallow when sown at 3 bushels/acre, but only moderate when sown at $\frac{1}{3}$ bushel/acre. A wheat crop sown at $\frac{1}{3}$ bushel/acre in 1957 was as effective as one sown at 3 bushels in carrying both diseases to the subsequent wheat crop. On the Rothamsted six-course rotation experiment, wheat was more severely infected by eyespot than ever before recorded, having 99 per cent straws infected, 81 per cent with severe lesions; this caused early lodging, and loss in grain, the yield being only 18·7 cwt./acre, as compared with the previous 20-year average of 30·4 cwt./acre. Spring-sown barley and autumn-sown rye in this experiment had respectively 22 and 15 per cent of their straws infected. These cereals grown in alternate years with non-susceptible crops carry enough infection to cause serious loss to winter wheat in the wetter years.

Spring-sown barley grown continuously on Hoos Field, usually only lightly infected, this year had eyespot causing lodging in small areas and take-all causing greying in larger areas. Spring-sown wheat, the fourth wheat crop in 5 years, was seriously affected by take-all in an experiment (Great Knott Field III) on levels and dates of application of nitrogen. On plots receiving 0, 2, 4, 6

cwt./acre " Nitro-chalk " 86, 29, 22, 14 per cent respectively of their areas were grey with take-all, and the very low yields of 8·5, 16·2, 20·2, 21·3 cwt./acre showed the depressing effects of this disease, which causes most loss in poorly nourished crops, and so increases the apparent response to nitrogen.

The severity of powdery mildew (*Erysiphe graminis*), on wheat was measured on randomly selected plants on Broadbalk plots by estimating the percentage area of the top two leaves covered by mildew pustules. The disease was most severe in the first crop after fallow of plots which had received nitrogen and phosphate; it was rather less severe where only nitrogen had been applied, and relatively slight on plots which had received potash as well as nitrogen and phosphate. (Glynne.)

Wheat grown in small pots containing Broadbalk soil, either untreated or with the pH altered by adding lime or sulphuric acid, had large root systems with negligible take-all in soil taken from Section II after a year under fallow. In soil which had carried four wheat crops (section VA and VB) there was much take-all with smaller root systems, except in acidified soils with pHs of about 4–5 in which take-all was negligible and root systems as large as those after fallow. At lower pHs the roots were damaged by acidity.

Cercosporella herpotrichoides isolated from wheat, barley, oats, rye and bent grass (*Agrostis stolonifera*) showed wide differences between isolates from either the same or different hosts in: (1) the numbers of spores produced on disks cut from pure cultures on potato dextrose agar; (2) in the time taken to produce eyespot lesions on wheat seedlings; and (3) in their effects on yield of grain. (Glynne and Cox.)

Survival of *Cercosporella herpotrichoides*, estimated by counting the number of straws on the soil surface which produced spores of the fungus incubated in the laboratory, was measured on two Broadbalk plots. In February to March on Section IV, where wheat had been grown in 1957, there were an average of 4·4 potentially infective pieces of straw per sq. yd. and 11 per cent of the plants in the 1958 wheat crop were infected in March, 17 per cent in April. On Section II, which had been fallow in 1957, there were only 0·2 pieces of infected straw per sq. yd.; no plants were found infected in March, and 1 per cent in April. (Cox.)

In the third and last year of a small-plot experiment measuring effects of sowing date, seed rate and nitrogen, Cappelle wheat was grown on rich land free from appreciable eyespot and take-all. The relative yield of each row was determined by sampling and the plot yields corrected to allow for the much bigger yield of the two outside rows. As in previous years, the corrected yields decreased with each delay in sowing and were 50·5, 47·7, 37·0, 35·6 cwt./acre for plots sown 26 September, 11 October, 8 November and 6 December respectively. The highest seed rate and higher levels of nitrogen increased lodging and therefore depressed yields. Mean yields of plots sown at $1\frac{1}{2}$, 3, $4\frac{1}{2}$ bushels/acre were 42·6, 44·1 and 33·6 cwt./acre. The effect of nitrogenous manuring is shown by plots sown at $4\frac{1}{2}$ bushels/acre, where plots receiving sulphate of ammonia at 0, 3, 6 and 9 cwt./acre yielded respectively 42·4, 39·6, 32·0, 20·6 cwt./acre

with 0, 5, 20, 62 per cent of their areas lodged. Nitrogen had little effect on yields of plots sown at 1½ and 3 bushels/acre. As in previous years, there was a small progressive decrease in yield from the second to the central rows in each plot, and this effect was most marked in the early sowing, so the effect of sowing dates on yields of the middle rows was small; sowings in successive months gave yields in the central rows (5 and 6) of 42·9, 43·2, 39·2 and 39·6 cwt./acre respectively. The wheat was attacked in spring by the larvae of dipterous insects, mainly *Opomyza florum*, and as in previous years the attack was heaviest on the early sown wheat. Wheat sown in September, October, November, December had respectively 58, 13, 4, 3 per cent plants and 18, 3, 1, 1 per cent shoots infested on 5 May, but as the larvae mostly attacked late-formed tillers, the effect on yield was not serious.

Results of this small-plot experiment were used to plan a larger replicated field experiment in which Cappelle wheat was sown at three dates, three seed rates with three levels of nitrogen on land virtually free from eyespot and take-all. The land was richer than that of the small-plot experiment, and in early June the crop looked better than any others at Rothamsted, but the rapid growth in spring and the continuous wet weather produced such lush growth that lodging began early, was very extensive, all plots were flat by harvest, and yield averaged only 30·7 cwt./acre. Here lodging limited yield, although Cappelle normally resists lodging. But the six discard rows separated from the harvested area of each plot by a blank row stood up well till just before harvest, suggesting that this device might enable us to obtain high yields on very fertile plots with less risk of lodging. (Glynne and Slope.)

The first series of the rotation experiment started last year provided a comparison of the incidence of eyespot and take-all in winter wheat (variety Heine 7) grown after winter wheat (W), barley (B), spring wheat (sW) and spring oats (O). The results are summarized in the table:

	% plants infected							
	Eyespot				Take-all			
Previous crops...	W	B	sW	O	W	B	sW	O
December 1957	0·3	0	0·7	0	23·6	17·1	44·9	0
March 1958 ...	7·4	12·4	0·6	0·5	26·8	25·7	51·8	0·6
May 1958 ...	4·9	14·8	0·8	0·5	52·8	44·4	74·0	0·9

The high percentage infection by take-all in December emphasizes the unusually favourable conditions for autumn survival and infection. The disease increased throughout the year, and at harvest the wheat after wheat, barley and spring wheat was very severely damaged. In contrast, the wheat after oats was a good crop. Reliable yields were not obtained because of a severe attack by birds; this attack was worst on the wheat after oats, which ripened several days later than the other crops. The percentage tailcorn (i.e., the grain that passed through a sieve with mesh size 20 × 2·2 mm.) was 14·7, 11·2, 11·1 and 5·7 for wheat after wheat, barley, spring wheat and oats respectively.

The site of the discontinued Deep Cultivation Rotation experiment on Long Hoos Field was used to obtain further evidence on the effect of previous crops on eyespot and take-all of winter wheat.

Yeoman wheat was sown in October on six areas that had the following crops in the years 1954–57:

(1) oats, sugar beet, barley, hay;
(2) wheat, potatoes, oats, barley;
(3) potatoes, oats, barley, barley;
(4) hay, wheat, barley, barley;
(5) barley, hay, wheat, barley;
(6) sugar beet, barley, hay, wheat.

In July the percentage of the straws with take-all was 2, 3, 2, 14, 21, 20, and with eyespot 44, 14, 8, 14, 39, 10 respectively. Thus take-all was slight only when there had been 2 consecutive years free from susceptible crops (wheat and barley) in the previous 4 years. In this experiment the incidence of eyespot was not related to the frequency of susceptible crops in the rotation. (Slope.)

Fusarium diseases of peas

Extensive field tests were made at Yaxley, near Peterborough, and at Rayne, Essex, to find sources of wilt-resistance among the pea varieties grown on a commercial scale in Britain. At both sites, where the soil was naturally infested with the wilt fungus, *Fursarium oxysporum* f. *pisi*, ninety pea varieties were sown in replicated plots. Records taken throughout the season showed that 50 per cent of the varieties were highly susceptible to wilt, among them most of the varieties that are popular and widely grown in this country. Some of the varieties susceptible in our tests had previously been found resistant in Holland and in New Zealand, probably because of differences in the geographical distribution of physiologic races of the fungus. Including evidence from previous observations and isolations from diseased plants, the reaction to wilt of 143 different pea varieties in Britain is now known. Of these, sixty-six varieties are susceptible. There was no correlation between wilt-resistance and any particular morphological feature of any group of varieties. Some susceptible seed stocks produced a few resistant plants, and these could be tested for suitability as breeding material. Tests of resistance in the glasshouse revealed that most methods of inoculation were unreliable guides to what may happen in the field, so it is unlikely that selection of resistant stocks can be speeded up in this way. The problem of control of pea wilt by using sources of resistance can now be handed over to plant breeders.

In further work on the interactions in the rhizosphere between root exudates from growing pea roots, soil micro-organisms and *Fusarium oxysporum* f. *pisi*, ninety-one different species of fungi and bacteria were isolated from the rhizosphere of peas and tested for their ability to inhibit the pea wilt *Fusarium* in culture. Of the sixteen that strongly inhibited the *Fusarium*, three had increased ability to inhibit when root exudate was added to the agar medium. These three organisms may exert an important effect on *F. oxysporum* in nature, in addition to the direct effects that root exudates have already been shown to exert on this pathogen. (Buxton.)

Further work on the mechanisms underlying the decrease in pea wilt that results from the presence of *F. solani* in plants infected

with *F. oxysporum* showed that water extracts from stems with foot-rot lesions contained two fractions, one stimulatory, the other inhibitory to *F. oxysporum*. When the concentration of the extract was reduced to $\frac{1}{10000}$, the stimulatory effect was nullified, and spore germination of the fungus was inhibited. *F. solani* colonized the epidermis and outer cortex more rapidly and more extensively than did *F. oxysporum*. It discoloured the cortex after 4 days, the invaded cells became packed with hyphae, and the cytoplasm later became granular and stained deeply with cotton blue. On the other hand, the hyphae of *F. oxysporum* passed both inter- and intracellularly through the epidermis and cortex; the root surface was not discoloured, the cortical cells remained intact and there was no obvious reaction in the cortex to invasion. The respiration rate of plants inoculated with *F. solani* was 25 per cent higher than that of uninoculated controls. From this and previous work it is concluded that the interaction between the two fungi occurs during growth in the cortex, where *F. oxysporum* may be delayed in its progress to the vascular track, resulting both in delay and ultimate decrease of wilt. (Buxton and Perry.)

Clubroot of crucifers

Studies of resting spore germination were resumed; all stages of germination and the free, presumptive, primary zoospores have been seen, and earlier observations confirmed. The readier tendency of spores from old galls to germinate spontaneously, compared with those from young galls, was again noted, but the level of germination was low. It has now been repeatedly confirmed that diffusate from the roots of cabbage seedlings, grown aseptically either in dilute Hoagland's solution or in dilute calcium chloride solution, stimulates spore germination. In one experiment, with a spore suspension containing initially, 1·5 per cent empty spores, 60 per cent were empty after 2 days incubation in solution containing root diffusate as against 15 per cent in solution alone. Differences in ionic composition of the medium also appear to influence germination, and this factor will require further examination.

Several small crucifers were tested for susceptibility to clubbing by three isolates of *P. brassicae*, but no differential effects were observed. *Arabidopsis thaliana* (L) Hynh. was the most susceptible of the plants tested, 100 per cent having symptoms of clubroot, followed by *Arabis alpina* (L) with 30 per cent, *Alyssum maritimum* Lam. with 22 per cent and *Cheiranthus allionii* Hort. with 10 per cent. *Aubrietia purpurea* (?) remained free from clubbing. (Macfarlane.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

In April D. W. Fenwick left to take a post in Trinidad. Elizabeth Widdowson also left in September. Audrey M. Shepherd, Patricia M. Nelson and J. E. Peachey joined the staff in February, July and September respectively. F. G. W. Jones was awarded a travel grant by the Rockefeller Foundation and, after taking part in the Golden Jubilee Meeting of the American Phytopathological Society in Bloomington, Indiana, U.S.A., spent eight weeks visiting research centres in the U.S.A. and Canada. The department provided an exhibit entitled " Root-Knot Eelworms " at Chelsea Flower Show and took part in the Symposium in Soil Zoology at Rothamsted, which preceded the meeting of the Zoological Congress in London. The work of the department continues to be greatly hampered by the lack of proper glasshouses and soil-handling facilities.

As in previous years, many specimens have been received for identification, including *Pratylenchus goodeyi* causing considerable damage to banana roots in the Canary Islands and *Pratylenchus coffeae* on tea roots from Ceylon. A number of new species have been encountered and will be described in due course.

J. B. Goodey has devoted most of his time to a revision and extension of the late T. Goodey's book *Soil and Freshwater Nematodes* (1951), which, when completed, will be a valuable contribution to nematology. The preparation of a supplement to *Nematode Parasites of Plants Catalogued under their Hosts* (2nd ed., 1956) is under way, and a list of plants resistant to root-knot eelworms is also being prepared (Goodey, Franklin, Hooper). Work on the genera *Meloidogyne* and *Aphelenchoides* has continued (Franklin). During the summer a visitor, Dr. V. H. Dropkin, tested the reaction of some pure lines of soybean to a native population of *Meloidogyne*.

Migratory Soil Nematodes

Population studies

The Rothamsted six-course rotation has been sampled at monthly intervals throughout most of 1958, and similar sampling of the Woburn six-course was started in September. Results to date suggest that the different crops and soil types have widely differing effects on the generic and specific constitution of the root-parasitic nematode fauna, but much more work is necessary before more positive conclusions can be drawn. Laboratory and greenhouse techniques to determine host efficacy and eelworm pathogenicity are being investigated, as a preliminary to possible outdoor tests in pots, microplots or field plots.

In collaboration with A. J. Gibbs (Plant Pathology Department), nematodes have been extracted from roots of sick and healthy plants and from soils from fields containing unthrifty patches of sugar beet attributed to " Docking disorder ". The results on the

whole have been inconclusive, but the fact that soils from some affected patches contain relatively few plant-parasitic nematodes suggests that the nematodes are not the cause of the disorder. Other nematode extractions done in connection with the same problem indicate that the application of 300 lb./acre of " DD Mixture " to Breckland soil in the winter of 1957–58 controlled two genera of migratory root nematodes; in November 1958 numbers of *Paratylenchus* in samples of treated soil were about 10 per cent of those in untreated soils, while the level of *Pratylenchus* was reduced much more—in fact, below detectable levels.

In collaboration with B. D. Harrison (Plant Pathology Department), nematode extractions have been made from samples of healthy and affected roots and from soils from various fields containing patches infested with ringspot viruses. To date, the numbers of root nematodes and occurrence of the viruses have not been closely correlated.

Further samples of " yellow-tuft " turf have been received from the Sports Turf Research Institute, but as no plant-parasitic nematodes were detected in one sample with typical symptoms nematodes did not cause this trouble.

Extraction techniques

The effects of chemical additives on the movement of nematodes and their extractability from soil were studied, but none greatly improved extraction. The Seinhorst mistifier and various modifications of it have been tested for extracting nematodes from soil. Although superior to the Baermann funnel in quantitative recovery from artificial samples, made by adding *Heterodera* larvae to nematode-free loam, it was no better, quantitatively, than a modified Baermann (in which a Petri-dish replace the conventional funnel), and had the disadvantage of delivering the nematodes in an inconveniently large volume of water. (Winslow.)

Feeding

During the last 2 years eight species of spear-bearing soil and plant nematodes have been successfully cultured on agar plates inoculated with *Agaricus hortensis* or *Alternaria tenuis*. For most species the former, although slow growing, is the better and gives a greater yield of larger worms. Twelve species of non-spear-bearing eelworms, including *Demaniella cibourgensis* and *Tricephalobus* sp., have also been successfully cultured on mixed bacterial colonies produced by seeding Nigon's agar with brewer's yeast. Successful culture on fungal plates of spear-bearing forms associated with plants, besides providing an abundance of specimens for description, also indicates that the species are not obligate parasites of the tissues of higher plants. Cultures also provide excellent material for the study of feeding habits and feeding mechanisms. (Hooper.)

Cyst-forming Nematodes of the Genus Heterodera

Potato-root eelworm (Heteroderea rostochiensis)

Joint work with A. J. Clarke (Biochemistry Department) has continued on the chemical nature of the hatching factor which

diffuses from potato roots into soil and induces the hatching of encysted eggs of the potato-root eelworms. The Nematology Department produces quantities of dilute crude factor by the leaching of potted potato plants. It also assays the crude diffusate and the various stages of its concentration and purification which, it is hoped, will lead to enough pure factor for chemical characterization. Altogether over 1,000 gallons of crude diffusate have been collected during the growing season, and attention has been turned to the production of factor from germinating tomato seeds during winter. In bioassays, well over a million potato-root eelworm cysts have been used. Two difficulties are encountered from time to time in the bioassay work: variability in the hatching rate of stocks of cysts and a decline in the potency of stocks of diffusate used as standards. Whether seasonal variability in the hatch from cysts is inherent, induced by external conditions, or a function of age is still uncertain. When stock samples of diffusate are kept for a year in the refrigerator at 2–4° C. their potency declines considerably, possibly from bacterial activity. However, decline is not prevented by the addition of a bacteriostat such as sulphur dioxide. In preliminary tests a purified form of the factor obtained by absorption on charcoal and elution with acetone has maintained activity over 26 weeks when stored in the refrigerator. Slight losses of activity occurred when stored at room temperature, especially when exposed to light. Attempts have been made to determine in greater detail than heretofore the form of the time-concentration curves for the hatch from cysts immersed in root diffusates and also to compare the results with the hatching responses of eggs freed from cysts. (Widdowson and Nelson.)

Cereal-root eelworm (Heterodera major)

Interesting results have been obtained from a long-term experiment on sandy soil in Shropshire in which oats, barley, wheat and rye were grown continuously on the same plots for 3 years. The experiment also compared autumn with spring sowing and fertilizer with no fertilizer. Starting with a reasonably uniform soil population level of cereal-root eelworm, autumn-sown oats raised the population most, whereas autumn-sown wheat and rye sown in autumn or spring reduced the population. The order of host efficiency was oats (best), barley, wheat, rye. Fertilizer tended to increase soil populations.

At Woburn an experiment has been started to find out whether the eelworm population can be reduced by ploughing-in trap crops of oats and rye before the cysts which develop on them mature. Both oats and rye are followed by a green manure crop (mustard) which is ploughed-in in the hope that increased organic matter will encourage eelworm predators.

To follow population changes under grasses, cocksfoot, timothy, Italian and Perennial ryegrass, and a mixture containing these grasses and late flowering red clover have been sown on small field plots also at Woburn. (Hesling.)

Pea-root eelworm (Heterodera göttingiana)

Work on pea-root eelworm has been increased. In an attempt to find when larvae leave the cysts, a pot experiment has been set

up to follow weekly changes in the soil population level. Cysts from the roots of spring-sown peas produced a partial second generation when added to clean soil sown with peas. (Hesling.)

Although larvae escape from cysts readily in the field at certain times, attempts to induce hatch and emergence in the laboratory have met with little success. This seriously handicaps various types of experimental work upon this important plant parasite. Laboratory hatching tests done in the standard way on batches of 100 cysts, immersed in various dilutions of pea-root diffusate in solid watch-glasses, give the same hatch as water, namely about 0·5 per cent of the egg content of the cysts in 3 weeks. Diffusate obtained in distilled water from germinated peas, and therefore free from ions and other contaminations contained in soil leachings that might inhibit hatch, was no better. Attempts to stimulate hatch by mixing cysts in sand or soil, by subjecting them to various temperatures, both constant and fluctuating, to chilling, drying and to the action of $10^{-2}M$ solutions of various simple organic and inorganic compounds have also failed to evoke response, as also have the root diffusates of several leguminous and non-leguminous plants. A slight increase in hatch (5 per cent in 9 weeks) occurred with improved aeration obtained by raising the cysts to the surface of pea-root diffusate on nylon sieves. Comparable tests with beet-eelworm cysts indicate that this method, and a similar one in which the sieve is moistened via a wick, gives cumulative hatches in 2 weeks that are four times those obtained by the standard watch-glass technique. (Shepherd.)

Beet eelworm (Heterodera schachtii)

In good hosts of the beet eelworm such as sugar beet and its allies and some species of Cruciferae, up to 45 per cent of the larvae used for inoculation entered the roots. The proportion of males and females that developed varied considerably. On the roots of the non-hosts *Chenopodium album* and *Beta patellaris* a few males developed and on *B. webbiana* very few: no mature females were observed on these plants. After invasion the highest death-rate occurred among second- and third-stage larvae. Those larvae that reached the fourth stage usually survived to maturity.

The hatching responses of *Heterodera* spp. to substances diffusing out from the roots of their host plants are often highly specific. During the course of the work mentioned above evidence was obtained which suggests that host finding by the larvae liberated from cysts is much less specific. Thus, many beet eelworm larvae invaded the roots of a range of non-host plants. The proportion invading non-hosts remained high even when planted in the same pot as the host, sugar beet. Similarly results were obtained in experiments with potato-root eelworm and pea-root eelworm. Besides indicating a low level of specificity in host finding, these experiments suggest that the attractant factor or factors, if such exist, which lead the larvae to plant roots are different from the hatching factors. (Shepherd.)

Other work on *Heterodera* spp. mentioned in previous reports, which is continuing, includes soil population studies (Doncaster), arthropod predators (Doncaster), biotypes breaking resistance of

potato varieties bred from *Solanum tuberosum* ssp. *andigena* (Jones), methods for culturing *in vitro* (Doncaster and Widdowson), chromosome numbers (Hesling) and *in vitro* tests of Vapam and Phosdrin. (Fenwick and Widdowson.)

Movement of Eelworms

Research on the movement of eelworms in soil and over plants has continued. In sand, movement depends on such factors as the rate of percolation of water, the particle size, the rate of movement of the eelworm and also upon its length and activity. Formulae linking the various factors have been derived. For a study of the movement of eelworms over plants, *Aphelenchoides ritzemabosi* on chrysanthemums was chosen. The theory that the eelworms are stimulated to move upwards against downward water currents in wet weather is untenable. Active movement upwards occurs in the absence of such currents, provided the plant bears sufficient moisture either as a continuous or discontinuous film. Movement is facilitated by hairs, which are more numerous on the upper parts of the plant. Invasion of leaves is via the stomata, and occurs during the drying-out phase. Under wet conditions adults and larvae emerge from the leaves via the stomata, often in great numbers. The implications of these observations on control by cultural or chemical means are to be followed up.

Work on the wave formation observed during the undulatory movement of different species has begun. By taking ciné films of eelworms moving in water films of varying thickness on agar, the properties of the waves formed by different species can be analysed and the characteristic movements of different species described quantitatively. Further work on the mobility of eelworms in soil confirms the view that mobility is influenced chiefly by the pore-size distribution and moisture content irrespective of soil type. Work on the relationship between hydrostatic pressure deficiency (pF) in the soil and the emergence of larvae from cysts of the beet eelworm has been resumed, the object being to determine the factors which influence emergence at different suctions. Low levels of emergence at high suctions appear to be associated with inability of larvae to escape out of cyst openings into the very thin water films in the soil. (Wallace.)

Special Photographic Techniques

Considerable use has been made during the year of the improvised photographic equipment mentioned in last year's Rothamsted report. Additional equipment for time-lapse filming of nematodes is being made. The ciné equipment has already proved valuable in studying feeding and feeding mechanisms, and in the analysis of movement of nematodes. Various types of culture chamber and perfusion chamber are being investigated for use in photographic observation of the various stages in nematode life cycles. (Doncaster.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

Daphne V. Holbrook and Elaine Fairey left and were replaced by Evelyn M. Brown and Gertrude Kruggel. F. T. Last returned from secondment to the Sudan.

Dr. Carlo Corral of the Instituto de Química "Alonso Barba" (Consejo Superior de Investigaciones Cientificas), Madrid, Dr. G. M. Das from India, Mr. McCallum Deighten of Mitchell Cotts and Co. Ltd., London and Mr. E. Mastrandeou from Greece worked in the department for various periods.

K. A. Lord attended the 4th International Congress of Biochemistry in Vienna, and visited laboratories in Austria, Holland, Germany and Switzerland where insecticides are studied.

At the request of Dr. A. D. Hanna, Chief of the Agricultural Research Division, Cotton Research Station, Wad Medani, C. Potter visited the Sudan to discuss the control of insect pests and diseases of cotton there. With Dr. A. B. P. Page, Reader in Entomology at the Imperial College of Science, he went to Uganda, Kenya, Tanganyika, Zanzibar and Southern Rhodesia primarily to study the work of the Colonial Pesticides Research Unit and to consider how the Unit might give more help to these territories. He also visited research laboratories of the Pyrethrum Board of Kenya in Nakuru to study the production and technical development of pyrethrum as an insecticide.

At the request of the Agricultural Research Council's Technical Committee on Insecticide, Fungicide and Herbicide Research, a conference of the research workers on plant protection under the chairmanship of Professor J. W. Munro was organized by the department and held at Rothamsted.

The new departmental glasshouse, though unfinished, is now being used. All four of the new constant-temperature constant-humidity rooms operated during the year and are used by several departments. There have been breakdowns and other difficulties, but it is hoped that these will be overcome. Work has been started on the three new constant-environment rooms.

Insecticides

Effect of temperature on the toxicity of insecticides

The work started by Dr. Das on the effect of temperature on the toxicity of DDT to mosquito larvae was continued. Larvae of *Aëdes aegypti* L. were exposed to DDT at 15° C. and 25° C. for short periods and then transferred to DDT-free rearing medium at 20° C. for 48 hours. DDT had a significantly greater effect on larvae exposed at 25° C. than at 15° C., which together with the results

of Das, indicates that mosquito larvae pick up more DDT at the higher temperature. (Needham.)

Isolation and properties of insect esterases

As part of the study of the biochemical mode of action of the organo-phosphorus insecticides, work on the isolation and properties of insect esterases was continued. The results previously reported on the properties of cholinesterase from the German cockroach *Blatella germanica* L. were confirmed and extended. Substrate concentration–enzyme activity curves have been obtained for the acetyl, propionyl and butyryl esters of choline, phenol, glycerol and ethanol. The same enzyme seems to hydrolyse all these substrates. The results show that the properties of the enzyme from the German cockroach resemble those of true cholinesterase of mammalian nervous tissues, but the cockroach cholinesterase has a higher affinity for choline esters. (Lord.)

Work on the hydrolysis of non-choline esters by breis of *Pieris brassicae* L. eggs indicated the presence of inhibitors in breis from newly laid eggs (0–12 hours old), and a method for their removal has been devised.

The purified extracts hydrolyse the acetyl, propionyl, butyryl and caproyl esters of phenol and glycerol. Inhibition studies with paraoxon indicate the presence of at least two enzymes; one is readily susceptible to inhibition, another is not inhibited by a concentration of paraoxon as high as $10^{-4}M$. As about 50 per cent of the susceptible enzyme is inhibited by a paraoxon concentration of $10^{-7}M$, it could be concerned in the poisoning process, and is therefore being examined in more detail. Preliminary experiments indicate that the inhibition kinetics may be of special interest.

Inhibitors were detected in breis from older eggs (5 days old at 20° C.), and their removal called for a method different from that effective with the young eggs. Purified breis from the older eggs also hydrolyse the acetyl, propionyl, butyryl and caproyl esters of phenol and glycerol. Inhibition studies also indicate the presence of at least two enzymes, one of which is still inhibited by paraoxon at $10^{-8}M$ whereas the other is not inhibited at $10^{-4}M$. Crude breis of the 5-day-old eggs hydrolyse esters of long-chain fatty acids, but it is not yet known whether purified breis do this. Esters of long-chain fatty acids are not hydrolysed either by crude or purified breis of new-laid eggs. (Solly.)

Toxicological and histochemical studies on the action of organo-phosphorus compounds on insect eggs

The permeability of the chorion, the specialization of the embryo, and the number and kind of enzymes present all alter with changes in age of the egg. Changes in susceptibility with age may therefore help towards an understanding of the mode of action of a poison. The effect of age on the susceptibility of eggs of the cabbage white butterfly *Pieris brassicae* L. to organo-phosphorus compounds was further studied. The methyl and *iso*propyl analogues of paraoxon, like paraoxon and dipterex, showed only small changes in toxicity with changes in the age of the eggs. Methyl paraoxon has about $\frac{1}{10}$ the toxicity of paraoxon and appears to increase in toxicity slightly

with increasing age of the egg. *iso*Propyl paraoxon has about $\frac{1}{100}$ the toxicity of paraoxon and appears to decrease slightly in toxicity with increase in age of the egg.

Small measured drops of paraoxon in acetone were applied to the base of the egg and to the micropylar end of eggs of *P. brassicae* throughout their development. No difference in toxicity with site of application was found until the eighth day at 16° C., which is 24 hours before the eggs were due to hatch; then the poison applied to the base was virtually non-toxic, whereas that applied to the micropylar end had approximately the same toxicity as to the previous stages.

Preliminary work on the effect of age on the susceptibility of eggs of house cricket *Gryllus domesticus* L. showed that TEPP was virtually non-toxic except when applied in the earliest stages of development. The toxicity of paraoxon decreases during the first few days of development and then increases slightly with increasing age. At the concentrations tested, full development occurs even when amounts lethal to larvae are applied. (Holbrook.)

The possibility that the poison remains in the chorion after application, and only reaches the embryo just before or during hatching was investigated by dissecting out embryos before hatching. Late-stage embryos from untreated eggs will complete their embryonic development in a Ringer solution, but in preliminary experiments with eggs poisoned with TEPP the embryos dissected out did not complete their development.

Experiments on the enzyme histochemistry of normal embryos of *P. brassicae* and those poisoned with TEPP were studied, together with the penetration by acetyl thiocholine through the embryonic cuticle, the general body tissues and the nerve sheath of older embryos. Treatment of the whole embryo, after removing the egg chorion, with a lipoid solvent, a wetting agent and a proteinase such as trypsin, assist penetration of acetyl thiocholine. An incubation of 2–8 hours at room temperature (20° C.) favours the reaction of the cholinesterase with the substrate. (Molloy.)

The action of organo-phosphorus insecticides on normal and resistant strains of houseflies (Musca domestica *L.*)

Of two strains of houseflies resistant to diazinon (0 : 0-diethyl 0-(2-*iso*propyl-6-methyl-4-pyrimidyl) phosphorothioate), one (Sacca), obtained from Dr. Sacca of Italy, maintained its resistance from generation to generation whether or not adult selection by exposure to the poison was practised in each generation. The other strain (203a), obtained from Dr. Keiding of Denmark, maintained its resistance to diazinon only when there was continual adult selection. Work on the mechanism of inheritance of resistance is being done in collaboration with Dr. H. Kalmus of the Galton Laboratory. Attempts to raise the level of resistance of the 203a strain by selecting at high mortality levels failed. Breeding from the survivors of selection at 75 per cent mortality presents difficulties, and an attempt is being made to improve the technique. (Fairey.)

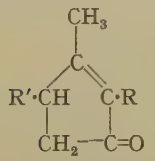
Histochemical studies by the Koelle technique on frozen sections of isolated brains of *M. domestica* suggest that acetylcholinesterase

is generally distributed throughout the tissue. There also seem to be localized centres of high cholinesterase activity, but more work is required before anything definite can be said. When brains of *M. domestica* poisoned with lethal doses (0·014 per cent w/v) of diazinon were examined by this technique staining was unaffected up to 24 hours after poisoning, indicating that the cholinesterase of the brain was not being inhibited.

The rate of penetration of organo-phosphorus insecticides is being studied with a labelled poison where penetration and localization can be measured by autoradiographs. (Molloy.)

Pyrethrins and related compounds

Relation between the chemical structure and the insecticidal activity of compounds related to the pyrethrins. A series of compounds related to the pyrethrins was prepared using furan compounds as precursors.



(I) R = $CH_2COOC_2H_5$
(II) R = $CH_2COOC_3H_7$
(III) R = $CH_2COOCH_2CH{-}CH_2$
(IV) R = $CH_2COOC_6H_5$
(V) R = CH_2COCH_3

The parent ketones (I–V, R′ = H) were brominated with *N*-bromosuccinimide and the resulting bromoketones were reacted with the silver salt of (±)-*trans*- or (±)-*cis-trans*-chrysanthemic acid. The structures of the intermediate bromoketones and hence of the esters (I–V, R′ = (±)-*trans*- or (±)-*cis-trans*-chysanthemoyl) were proved by showing that more than 80 per cent of the bromine introduced could be removed as hydrogen bromide by very mild treatment with trimethylamine. These are the first esters related to the pyrethrins to be prepared with ester or keto functional groups in the β position of the alcoholic side chain.

Preliminary bioassay results, using mustard beetles and a measured-drop technique, indicate that these groups do not produce such a high insecticidal activity in the molecule as that produced by one double bond (e.g., cinerins I and II and allethrin) or by conjugated double bonds (e.g., pyrethrins I and II). (Corral and Elliott.)

Isolation, examination and properties of the insecticidal constituents of pyrethrum extract. Work on the isolation and purification of the alcoholic constituents of the pyrethrins has continued. After preparing pure (+)-pyrethrolone by techniques which have enabled adequate supplies of pure pyrethrin I and pyrethrin II to be reconstituted, attention was given to making (+)-cinerolone so that cinerin I and cinerin II may be reconstituted in a similar manner. (+)-cinerolone hydrate has now been obtained as a low-melting crystalline solid.

The optical rotation of pure undistilled pyrethrin I $[\alpha]_D^{20}$ –13·4° changes greatly on distillation, the extent depending on the heating conditions. The rotation of cinerin I is unchanged on heating, so the change with pyrethrin I is most likely to be associated with the isomerization of the double bonds in the side chain. It follows that

any distilled samples of pyrethrin I or pyrethrin II may contain some isomeric esters. This can explain some of the inconsistent optical rotations recorded in the literature and could affect estimates of toxicity. The work on isomerization was helped by the gift by Dr. M. Thain of the Tropical Products Institute of a generous sample of pure pyrethrin I obtained by chromatography of the natural material. This permitted a definitive measurement of the optical rotation to be made. (Elliott.)

Examination of the crude pyrethrum extract for additional insecticidal compounds. This work (on the biological activity of fractions of a crude pyrethrum extract from the Belgian Congo, rich in cinerins) is being done in collaboration with Dr. Thain of the Tropical Products Institute, who is concerned with the chemical investigations.

The capacity of nitromethane to extract all the substances with insecticidal activity from the crude extract was studied as part of an investigation into the possibilities of producing pyrethrum extracts which do not stain. After seven successive extractions with nitromethane all the biological activity is transferred to the nitromethane portion and none remains in the crude extract. The recombined extract made up from the nitromethane extracted material and the residue is equal in toxicity to the crude extract and the nitromethane portion. Therefore, judged on the mortality of houseflies after 24 hours, it is unlikely that the residue contains any substance which could activate the insecticidal material present in the nitromethane fraction. (Sawicki and Elliott.)

Synergists for pyrethrum. At the request of the British Petroleum Company the effect on the toxicity of pyrethrum of adding diphenyl methane was compared with that of piperonyl butoxide using the flour beetle *Tribolium castaneum* Hbst. A measured drop technique was used, together with an after-treatment temperature of 20° C., a 7-day inspection time and ratios of pyrethrins to possible synergist of 1 : 1, 1 : 2·5, 1 : 4 and 1 : 9. No evidence of synergism was found with the diphenyl methane; indeed, the toxicity of the pyrethrins was consistently lower in the presence of the diphenyl methane, although the difference was not significant.

Piperonyl butoxide applied in the same way showed some syngeristic effects, for the mixture was 1·36 times as toxic as the extract at the 1 : 1 ratio and 2·4 times as toxic at the 1 : 9 ratio. (McCallum Deighton.)

Four substances have been claimed to activate pyrethrum extract: piperonyl butoxide (3 : 4-methylenedioxy-6-propylbenzyl *n*-butyl diethyleneglycol ether), " Sesoxane " (2-(2-ethoxyethoxy) ethyl-3 : 4-methylene-dioxyphenyl acetal of acetaldehyde), " S.421 " (octochlorodipropyl ether) and " B.P.50 " (diphenyl methane). The synergism of these substances was tested by a measured-drop technique, at fixed ratios with pyrethrum, on 5–6-day-old female houseflies with an after-treatment temperature of 20° C. and an inspection time of 24 hours. Acetone was used as the solvent. The ratios of synergist to pyrethrins were 1 : 1, 1 : 2, 1 : 4, 1 : 8 and 1 : 20. " Sesoxane ", piperonyl butoxide and " S.431 " all increased the activity of the extract. " Sesoxane " had most activity, closely followed by piperonyl butoxide; " S.421 " was considerably less

active. Diphenyl methane depressed activity, as also found with *Tribolium castaneum.*

To determine whether these materials act simply as synergists or whether they are insecticides, their toxicity when applied alone was tested. Another syngerist, " Bucarpolate " (the ester of piperonylic acid with mono-*n*-butyl ether of diethylene glycol) was included: it was non-toxic 24 hours after dosing and $\frac{1}{2500}$ the toxicity of pyrethrin after 48 hours. " Sesoxane " had $\frac{1}{50}$ and piperonyl butoxide $\frac{1}{100}$ the toxicity of pyrethrum to houseflies, 24 hours after dosing. The flies were not knocked down by these compounds. " S.421 " was fairly toxic, about $\frac{1}{10}$ the toxicity of pyrethrum; it also had a definite knockdown action. (Sawicki.)

Physiological studies on the mode of action of pyrethrins

As pyrethrum is often stated to act as a nerve poison, the action of pyrethrins on the insect nervous system is being studied by measuring their effects on the membrane potentials, both normal and anoxic, of the giant fibre axons of the American cockroach *Periplaneta americana* L. Pyrethrin I (reconstituted from the naturally-derived alcohol and acid) depresses the normal membrane potential slightly, to an extent that is roughly proportional to its concentration; the depression is negligible at $10^{-6}M$ and about 12 per cent at $10^{-3}M$. At the lower concentrations the membrane potential recovers slightly after its initial depression. As the anoxic membrane potentials were less steady, it was more difficult to measure the effects of pyrethrin I on them; however, they appeared to be depressed about the same extent as the normal potentials. Pyrethrin I delayed the return of the anoxic membrane potentials to normal levels when nerves were restored to oxygen. (+)-allylrethronyl(+)-*trans*-chrysanthemate and α-(±)-*trans*-allethrin had much less effect than pyrethrin I on the membrane potentials, though there were small depressions at $10^{-3}M$. There appeared to be little difference between these two compounds, but there is not yet enough information to draw reliable conclusions. (Burt and Weevers.)

Toxicity and persistence of insecticidal deposits

A method for assaying toxicity of residual films of insecticide using adult *Musca domestica* L. was developed and is described in the next section. It permits short exposure times, whereas long exposures are necessary with adult *Tribolium castaneum* Hbst. Plates sprayed with a DDT emulsion consisting of 0·1 per cent w/v DDT, 0·3 per cent v/v xylene and 0·1 per cent w/v lissapol N in water gave rather variable results, probably because of irregular crystallization. The plates increased in toxicity for at least 2 days after spraying. Plates sprayed with a solution of DDT in 78 per cent v/v xylene, 20 per cent v/v ethyl cellosolve (ethylene glycol monoethyl ether) and 2 per cent v/v medicinal paraffin gave more reproducible results. The concentrations tested ranged between 0·05 and 0·5 per cent w/v DDT, and with this formulation the film remained liquid on storage. This liquid paraffin formulation is more toxic on either plain or wax-coated plates than on cabbage leaves. The emulsion deposits, by contrast, are more toxic on

leaves than on plates. A suspension of 60μ needle crystals of DDT containing 0·1 per cent w/v sulphonated lorol, 10 per cent v/v ethyl alcohol and 90 per cent water gives a more toxic deposit than the emulsion on both plates and leaves. These relative toxicities, determined with houseflies and exposure times of 2–8 minutes, may differ with other species and longer exposure times. (Ward and Gillham.)

Chemical analytical techniques

Work on the analysis of BHC in soil was resumed. The method previously used (*Rep. Rothamst. exp. Sta for 1956*) was unsatisfactory with soils rich in organic matter and gave erratic results with some other soils. It was found that steam distillation of BHC from the soil gave either incomplete extraction or, when superheated steam was used, there was some decomposition. Solvent extraction gave an extract with a lot of interfering matter which could not easily be removed. The Schechter–Hornstein method for BHC estimation was also investigated in conjunction with solvent extraction of the soil, but without satisfactory results. Nitration of the residue from soil extract followed by reduction with titanous chloride appears promising, but has not yet been fully investigated. (Ward and Jeffs.)

Bioassay techniques and standardization of test insects

Bioassay of contact toxicity of insecticide deposits. In the bioassay method using adult houseflies (*Musca domestica* L.), the flies are chilled, then sorted into batches of ten and allowed to recover. Each batch of ten is then exposed to the treated surface in an exposure chamber. The base of the chamber is perspex with a glass plate for the floor. The glass plate can be slid out and replaced by the treated surface. The side of the chamber is a metal ring cooled by circulating ice water to make it repel the flies. The top of the chamber is of perspex, with a hole for the introduction of the test insects. The exposure chamber is placed on a plate kept at 30–35° C. and the glass plate on the floor allowed to warm to this temperature. The test insects are introduced and allowed to settle down on the attractive warm surface. The test surface, now at the temperature of the warm plate, is slid in to replace the glass plate as the floor of the chamber, and the flies settle on it. Ice may be placed on the roof of the chamber to make it repellent. After the given exposure time the flies are anaesthetized and removed to clean tubes. They are allowed to feed on sugar water during the 24-hour holding period at 20° C., after which mortality is assessed.

This method of bioassay gives results with shorter exposure times and is more sensitive than the one formerly used with *Tribolium castaneum* Hbst. as test insect. (Ward and Gillham.)

Standardization of Musca domestica *L. for bioassay of the contact toxicity of pyrethrin-type molecules.* Improved methods of rearing and standardization of houseflies for bioassay tests on the pyrethrins have been developed. Female houseflies oviposit more readily on cotton-wool packs soaked with a solution containing 30 per cent yeast and 60 per cent milk than on milk-soaked packs or bran. Eggs can be simply separated from the ovipositing medium and a

technique has been developed for inoculating the medium with a constant number. Substituting polythene wash bowls 12 inches diameter for jam jars allows the amount of medium required to rear 5,000 flies to be halved, for the larvae do not burrow below a depth of 1 inch in the medium. This is probably because the semi-liquid state of the food causes the tunnels to collapse, depriving the burrowing larvae of air. The collected pupae are cleaned and weighed and larval mortality and pupal weight recorded. The figures have been fairly constant since the rearing technique has been standardized.

Only flies that emerge within a given 24 hours are used. Females are sorted on the fourth day after emergence and dosed on the fifth. The insects are kept in the rearing room at 27° C. until dosing; after treatment they are kept at 20° C. Although the post-treatment life of these flies is shorter than with younger flies, the end point, i.e., the point beyond which no appreciable recovery or additional kill takes place, is reached within 24 hours. This was confirmed when flies lived for 48 hours.

The rather high mortality of the young larvae (about 30 per cent) was investigated, but no explanation was found. Eggs that float in water are not necessarily infertile. Most of the eggs laid within 6 hours are hydrophobic and float for some time before sinking. About 10 per cent of the eggs which sink do not hatch within 24 hours at 28° C.

The addition of vitamins A, D and C was not significantly beneficial, and at high doses was detrimental to the larvae. The addition of cholesterol to the medium did not affect weight or the mortality of the larvae, although it has been claimed to increase the weight.

Preliminary results suggest that although the variation in the population density of the larvae affects the pupal and imaginal weights, the influence of variation in weight, within the limits tested, on the results of bioassay with pyrethrins is not statistically significant. By the standardization of the breeding and handling techniques, fluctuations in the LD50 values were so decreased as to obtain reproducible results from week to week. (Sawicki.)

Detection and identification of toxic substances in poisoned bees

Eight samples of bees submitted during the year were examined for insecticide. Three were found to contain an esterase-inhibiting material; from the details submitted by the beekeepers it seems likely that the bees had been poisoned by parathion. One sample, thought to have been exposed to lead arsenate, contained 1·6 μg. of arsenic per bee, which is enough to account for the deaths. One further sample contained metabolized DDT. No residues were found in the remaining three samples; of these, two came from fields known to be near fields of beans sprayed with " Metasystox " just before the bees died.

A bioassay method is used in the preliminary examination for the presence of insecticide, and mosquito larvae (*Aedes aegypti*) had previously been used as the test insect. As the toxicity of extraneous material in the extracts caused difficulties, an alternative method was developed using adult fruitflies (*Drosophila melanogaster*

Meig). Tubes were coated with a deposit of the extract and the test insects exposed to the deposit for 2 hours and then transferred to clean tubes containing food for a further period of 24 hours at 28° C., when the mortality was assessed. An even coating on the tube was obtained by dissolving the extract in low-boiling petroleum ether and rotating the tube in a horizontal position in a special device while the solvent was evaporated off. With this technique, extraneous materials were not a problem, but the method proved limited because the test insects were particularly insensitive to DDT and not very sensitive to " Metasystox ". Improved methods of separating the insecticide from the extraneous materials have now been developed, and with these purified extracts bioassay tests using mosquito larvae have been giving good results.

Samples of bees submitted during the past two summers thought by beekeepers to have been poisoned with " Metasystox " have not yet been found to contain material toxic to mosquito larvae. Mosquito larvae are not very sensitive to " Metasystox " (threshold about 0·8 p.p.m.), but " Metasystox " is not very toxic to bees, the oral LD50 being about 1 μg. per bee, so that poisoned bees should contain a detectable residue if there were no decomposition. A test was made to determine whether the " Metasystox " was liable to decompose in the dead bees between the time of poisoning and extraction. The bees were treated with 3 μg. of " Metasystox " by topical application and kept at 20° C. after treatment. Determinations of loss of " Metasystox " with time were made by mosquito larvae bioassays and esterase-inhibition tests. The bioassay tests indicated that some insecticidal material was left in the bees after 8 days, but this was not detectable by the esterase-inhibition tests. However, as the samples sent by beekeepers had often been exposed to sun and rain before the sample was taken and were rarely received in under 5 days, weathering may explain the failure to detect the poison.

Dinitro-*o*-cresol, which has a low toxicity to the larvae of *Aëdes aegypti* and to adult *Drosophila melanogaster* Meig., is highly toxic to bees. A colorimetric method for detecting DNC in the extracts has been developed, depending on the partition coefficient of the DNC in different solvents and the development of the yellow colour in a buffer solution at a pH of 7·5. This test is relatively non-specific. As smaller amounts of DNC than expected have been found in poisoned bees, a test with the colorimetric method was made with this poison to determine the loss of insecticide with time. The conditions of the test were the same as those for " Metasystox ". The amount of DNC diminished with time of keeping, but was still detectable after 8 days.

A more specific sensitive spot-test for DNC was developed. It consists of putting a spot of the bee extract on filter-paper, treating with titanous chloride and exposing to bromine vapour, when the DNC gives a purple colour. This test failed even with bees extracted 3 hours after applying DNC, probably because the colour was masked by coloured extractives from the bees. (Ward and Needham.)

Insect rearing

The following insects were reared in the department during the year:

	Plant feeding
Hemiptera	*Megoura viciae* Buck.
	Aphis fabae Scop.
	Acyrthosiphon pisum Harris.
	Myzus circumflexus Buck.
Lepidoptera	*Pieris brassicae* L.
	Diataraxia oleracea L.
	Plutella maculipennis Curtis.
Coleoptera	*Phaedon cochleariae* F.
Diptera	*Leptohylemyia coarctata* Fall.
	Hylemyia antiqua Meig.
	Chortophila brassicae Bouché.

	Stored product, domestic and medical
Orthoptera	*Blatella germanica* L.
	Blatta orientalis L.
	Periplaneta americana L.
	Gryllus domesticus L.
Coleoptera	*Oryzaephilus surinamensis* L.
	Oryzaephilus mercator Fouv.
	Tribolium castaneum Hbst.
	Tribolium confusum Duval.
	Tenebrio molitor L.
	Trogoderma granarium Everts.
Diptera	*Aëdes aegypti* L.
	Drosophila melanogaster Meig.
	Musca domestica L.

The technique of rearing *Pieris brassicae* L. was modified to avoid handling the adults.

Wheat-bulb-fly (Leptohylemyia coarctata *Fall.*) *control*

Box experiment. Insecticides tested as seed dressings included " Disyston ", phenyl mercury monofluoro acetate and its ammonium carbonate complex, " Phosdrin ", " Rogor " and " Thiodan ". " Thiodan " was the only material to show any promise, but was not obviously superior to dieldrin and heptachlor, which are being used in the field experiments.

Field experiments. Experiments at Newborough near Peterborough and Southwick, Northants, in collaboration with Dr. H. C. Gough and his colleagues of the National Agricultural Advisory Service, tested the effect of seed dressings applied at two to twelve times the conventional dosage rate. The insecticides used were aldrin, dieldrin and heptachlor applied in an aqueous solution of methyl-cellulose to bind the toxic material to the seed. At Newborough, where there was a heavy wheat-bulb-fly attack, all three insecticides greatly increased yield, from 11·5 cwt./acre for the untreated to 25·2–27·6 cwt./acre for the treated. Heptachlor

appeared slightly better than aldrin and dieldrin, and the dressings at the rate of 1 per cent insecticide to weight of seed were only a little better than the 0·15 per cent rate. The seed treatments were superior to combine-drill treatments with aldrin and dieldrin at 1·5 lb./acre, which gave yields of 19·7 and 17·0 cwt./acre respectively.

Results at Southwick, where the attack was less severe, were comparable. This trial included a standard seed dressing with 40 per cent γ-BHC at 2 oz./bushel of seed. This proved inferior to the other dressings, perhaps because the early November sowing is less favourable to BHC than the other chlorinated hydrocarbons. None of the seed dressings were phytotoxic. (Bardner.)

Bean aphid (Aphis fabae *Scop.*) *control*

Effect of plant density of spring-sown beans on infestation and control. The effect of plant density of sprayed and unsprayed crops on yield of spring beans was studied. Beans were sown on 18 March 1958 in rows 22 inches apart to give six levels of plant density ranging from 5·3 to 106 plants/yard of row. Each plot was split for spraying with demeton methyl at 6 fluid oz. of active ingredient per acre for aphid control, versus unsprayed. The results are given in Table 1.

TABLE 1

Plants per yard row	5·3	11·3	20·7	41·4	57·0	106·0
Yield (cwt./acre):						
Untreated ...	16·6	24·2	27·9	27·9	26·2	20·5
Treated	24·1	31·2	32·3	29·8	25·1	21·3

The aphid counts have not yet been analysed, but it is evident that initial infestation and subsequent build-up was greatest, both on individual plants and per unit area of plot, where there was a thin plant stand. There were few aphids in plots with 57 and 106 plants per yard of row, and this is reflected in the yield, which did not benefit from the spray. As the plant population fell yield increases from spraying rose. (Way and Doherty.)

Natural control in relation to chemical control. This work was continued in collaboration with C. J. Banks of the Entomology Department. *A. fabae* laid many eggs in the autumn on some of the *Euonymus europaeus* bushes selected for study. Some hatched in February 1958, but did not survive the long cold period in March. Overwintering adults of Coccinellid and Anthocorid predators were abundant in April and May. The Coccinellids were probably plentiful because the big populations of many aphid species in May–July 1957 provided a good food supply. The predators helped to reduce the *A. fabae* populations on the winter host and also destroyed many young colonies developing later on the summer hosts—field beans, *Vicia faba* and fat hen, *Chenopodium album*—on which counts were made periodically.

Revised sampling methods, whereby plants were examined in detail in the laboratory, showed that Syrphid larvae preying on the aphids were abundant in July on summer hosts. These new sampling methods also showed that some of the previous methods were inadequate for the examination of numbers of larval predators.

Unsuitable weather and natural enemies kept *A. fabae* populations lower from May to July than might have been expected from the many overwintering eggs on some *E. europaeus* bushes. Small populations remained on the summer hosts (field beans, sugar beet and fat hen) from August to October, from which migrants returned to *E. europaeus*, where large numbers developed in some bushes in October and November. (Way.)

Control of potato virus spread

Work in collaboration with the Plant Pathology Department on the control of potato virus spread continued, and the experiment on spray timing done in 1957 was repeated; it is described in the report of the Plant Pathology Department (p. 101 above).

In 1957 " Thimet " (*O, O*-diethyl *S*-(ethylthionomethyl) phosphorothiolothionate) mixed with activated charcoal and placed under potato tubers at planting time prevented aphids from breeding on the plants for at least 4 weeks after the plants emerged. This year this type of treatment was tested to see whether it could produce healthy seed tubers by controlling aphids on the plants until roguing became possible.

Four treatments were tested:

(1) Individual doses of " Thimet " with activated charcoal were placed below each tuber, each dose containing 0·31 g. of active ingredient.

(2) The same " Thimet " formulation applied at the same rate but mixed with granular fertilizer and applied evenly along the row.

(3) " Rogor " (*O, O*-dimethyl S-(*N*-methylcarbamoylmethyl) phosphorothiolothionate), with activated charcoal applied in the same way as treatment (1) at the rate of 0·35 g. of active ingredient per tuber.

(4) A control untreated.

The cost of the treatments (1) and (2) was slightly greater than that of spraying three times with DDT emulsion at 2 lb. of active ingredient per acre. Greenhouse tests showed that the treatments were only slightly toxic to the potatoes. Each treatment was repeated four times, and each plot contained one tuber with leaf roll and one with virus Y. The tubers were planted on 21 April, and all the plants had emerged by 6 June.

Aphids were counted throughout the season; treatments (2) and (3) kept the plants almost free from aphids throughout the period when they were present in the rest of the crop, and treatment (1) was only slightly less efficient. Plants given treatment (2) became aphicidal a little earlier than those in other plots.

Tests using laboratory-reared aphids confined on the plants by sleeves showed that the plants were still toxic to aphids in mid-August, although by then their toxicity was diminishing. Plant heights were measured three times during the season; treatments (2) and (3) caused very slight stunting. Treatment (3) caused a little browning of the leaf edges. At lifting there were only small decreases in yield in treatments (2) and (3) and none in (1). There were no significant differences between the yields from any of the

treated plots and the control. The infector plants were rogued on 25 June, about a week after it had become possible to recognize them with certainty as diseased. Just before lifting, tuber samples were taken from plants near the infectors to estimate virus spread. The amount of spread will not be known until next year.

In mid-November the toxic residues in the tubers after lifting were kindly estimated by Dr. E. I. Johnson of the Government Chemical Laboratory. Chloroform-soluble extracts of the tubers were examined for anticholinesterase activity. Tubers from the control plots showed no activity; those from treatment (1) showed a trace, those from (2) showed activity equivalent to 3 p.p.m. " Thimet " and those from (3) activity equal to 5 p.p.m. of " Rogor ". A chemical method showed that tubers from treatment (3) contained not more than 0·1 p.p.m. of " Rogor " or any other chloroform-soluble phosphorus-containing residue. It seems likely that the tubers contained cholinesterase-inhibiting metabolites of greater activity than the insecticides from which they were derived. It is proposed also to make insecticidal bioassay tests for residues.

The effect of the distance between the insecticide and the tuber on aphicidal potency was investigated by placing a dose of 0·31 g. of " Thimet " mixed with activated charcoal at different distances from the tuber. The five treatments were: (1) no " Thimet "; (2) " Thimet " just below tuber; (3) " Thimet " 3 inches to one side of each tuber; (4) " Thimet " 6 inches to one side of each tuber; (5) " Thimet " combined with the fertilizer and applied evenly along the row. The tubers were planted on 21 April. Four sleeve tests were made, the first on 3 June at 95 per cent emergence of the plants and the last on 15 July. Treatment (5) was the most effective and caused almost 100 per cent mortality in all tests except the earliest which shows that the aphicide did not appear in the plants at its most effective concentration until a little after the shoots emerged. Of plants derived from tubers dosed individually with " Thimet ", those from tubers separated by distances of 3 inches and 6 inches took longer to become aphicidal than those in contact with it. The greater the distance, the greater was the delay. Treatment (2) was consistently more effective than treatments (3) and (4), which were about equally effective after the first test. It is concluded that where potatoes are dosed individually the insecticide should be placed as close as possible to the tuber for maximum efficiency. (Burt, Broadbent and Heathcote.)

Pests of mustard

As part of collaboration with Dr. H. C. Gough of the N.A.A.S. and Messrs. Colman, work started on the pests of mustard, particularly of *Brassica juncea* var. Trowse. The damage caused by *Meligethes aeneus* and its related species, *Ceutorrhynchus quadridens* and *C. assimilis*, on four test species of brassica, White mustard (*Brassica alba*, indigenous), Brown mustard (*Brassica juncea* var. Trowse, exotic, Radish (*Raphanus sativus*, indigenous) and Chinese cabbage (*Brassica cernua*, exotic) was studied. In general, the two exotic varieties were more susceptible to attack and damage by all the insect pests than were the two indigenous species. A collection of the parasites and predators of the pests is being made. (Doherty.)

Seed treatment with insecticides

Seed treatment with insecticides is a convenient and effective method of controlling some insect pests, and work was done on methods of formulating and applying insecticides to seeds and on their mode of action. One of the limitations of seed dressing is that relatively small amounts of active material will adhere to the seed unless special formulations are used, and various methods of applying liquid and solid insecticides were examined, using wheat and white mustard as test seeds. The stickers and fillers tested included aqueous emulsions of polyvinyl acetate and polystyrene, aqueous solutions of polyvinyl alcohol and methyl cellulose, polyethylene glycol, a siliceous earth, activated carbon and various proprietary insecticide fillers. Materials used in the formulation can affect the toxicity of the active ingredient, both to the insect and to the plant. Under some conditions both activated carbon and polyvinyl acetate depress the insecticidal activity of " Thimet ", γ-BHC and dieldrin, and decrease the phytoxic effects of " Thimet " and γ-BHC. This may have considerable practical implications, because carbon is being used increasingly as a carrier for liquid organo-phosphorus insecticides. The possibility that the length of time the seed-dressing remains effective may be prolonged by means of materials in the formulation is being investigated.

Results this year confirmed that seed-dressings are more toxic to plants and insects in sand than in soil. (Bardner.)

Further laboratory and field trials on the mode of action of dieldrin and γ-BHC when used as a seed-dressing against the wheat-bulb fly *Leptohylemyia coarctata* Fall. showed that kill by dieldrin, probably by contact action only, occurred when treated seed was shallowly sown, i.e., less than 1 inch from the soil surface. These results fall into line with those in which it was shown that most larvae come close to the soil surface before searching for and attacking a host plant, irrespective of the position of the egg from which they hatch. Deep sowing not only reduced kill by contact action of dieldrin outside the plant but also greatly reduced kill by systemic action after the larvae had entered the plant. Thus in one field trial using wheat dressed with 0·058 mg. dieldrin per seed, the percentage kills of larvae which entered the plant was 64 for sowings $\frac{1}{2}$ inch deep and 0 for sowings 3 inches deep.

Preliminary experiments on the action of seed-dressings for the control of the onion fly *Delia antiqua* Meig. showed that dieldrin could prevent damage, probably because it killed the larvae by contact before they attacked the host plant. The choice of the underside of the bulb as the site of entry, even when the seed is sown 1 inch deep, ensures that the larva passes close to the treated seed. The evidence obtained indicated that the larvae were not killed by systemic action after entry in the plant.

Experiments with dieldrin seed-dressing on oat and wheat seed for the control of frit fly *Oscinella frit* L. showed that some larvae, probably those hatching from eggs in the soil, were killed by contact action outside the plant when the seed was shallow sown, but there was little or no effect when the seed was sown 1 or more inches deep. There was no evidence of systemic action, and thus, in prac-

tice, a dieldrin seed-dressing is not likely to be of value in Frit fly control.

The difference in the effectiveness of dieldrin seed-dressings for the control of these three pests may depend on differences in the environmental conditions when the attack occurs and differences in larval behaviour, as well as differences in absolute resistance of the larvae. Wheat-bulb-fly larvae may be poisoned on the way to the plant, and if not they go down to the growing point soon after entry, where there is likely to be a lethal concentration of poison in the tissues. Onion fly enters via the base of the bulb, and thus is likely to go through a zone of poison before entry. Apparently the conditions of growth are such that a lethal concentration of poison is not built up in the tissues of the onion. The frit-fly larva may enter the plant either above or below ground and does not necessarily pass through a zone of poison before entering the plant. Once in the plant, it may feed and not descend to the growing point for some time, and it is not therefore liable to be killed within the plant, even when the conditions of growth at the time of the year allow the presence of a lethal concentration in the tissues at the base of the plant. (Way.)

Fungicides

Results of spore-germination tests

Evaporation. It is common practice when making spore-germination tests with fungicides to contain drops of spore suspensions in moist chambers on microscope slides. It has been assumed that the volume of the drop, and hence the concentration of the fungicide in the drop, will remain constant, but this is not so. Changes in volume of drops have been followed by measuring the change in concentration of a dilute solution of dye (Naphthalene Scarlet 4 RS). When Böttcher's slides containing 0·3-ml. drops are kept at a constant temperature, the volume usually decreases by about 7 per cent in 48 hours. The size of the loss depends on the conditions. It may be as much as 47 per cent; or water vapour from the water seal may even condense on the drop and increase in volume by about 5 per cent.

Loss of mercury compounds on glass and other surfaces. Glass surfaces remove mercury from neutral aqueous solutions of inorganic mercury compounds. This may appreciably lower the nominal concentration of mercury in the course of spore-germination tests. The extent of these losses has been investigated. The proportion of mercury lost increases with time of contact with the surface, with the area of contact and with the degree of dilution. On microscope slides the losses increase with increase in temperature in the range 10–25° C. The losses may occur during serial dilution of the solutions and on the microscope slides themselves. Thus, when a solution of mercuric chloride containing 60 mg. Hg/litre is diluted in three stages to 1·0 mg. Hg/litre in soda-glass tubes, the loss in strength of the final solution is about 25 per cent. When 0·3-ml. drops of mercuric chloride solution, containing 1·0 mg. Hg/litre, are placed on glass Böttcher's slides under cover-glasses, the losses are 15 per cent in 15 minutes and 60 per cent in 24 hours. The

combined loss from both stages (tubes and slides) is over 70 per cent in 24 hours. Cavity slides have been made from perspex and polystyrene sheet. The losses on perspex slides are almost the same as on glass; it is likely that the losses on polystyrene will be less.

The uptake of phenyl mercuric acetate by glass from neutral solutions is small. Thus, the loss on Böttcher's slides from 0·3-ml. drops containing 1·0 mg. Hg litre is only about 7 per cent in 24 hours, compared with 60 per cent for mercuric chloride. The loss on perspex slides is about 35 per cent.

Spores take up mercury rapidly from solution, so that in a spore germination test the mercury will be taken up by the spores and by the surface of the slide as well. The same may be true of other water-soluble fungicides.

The effect of temperature on the toxicity of fungicides

Five strains of *Botrytis fabae* Sardiña were obtained from other laboratories and tests made to determine the temperature coefficient of toxicity of aqueous solutions of mercuric chloride to spores of these strains, and to one strain of *Botrytis cinerea* Pers. ex. Fr. and one of *Sclerotinia laxa* Aderh. & Ruhl. With none of these fungi was the temperature coefficient (10–25° C.) of a significant size, so the results obtained earlier with mercury salts on the Rothamsted strain of *B. fabae* seem to be peculiar to that strain. (McIntosh.)

ENTOMOLOGY DEPARTMENT

K. Mellanby

P. W. Murphy, who had been working on the biology of forest soils since 1951, left in September 1958 on appointment as lecturer in Agricultural Zoology in the University of Nottingham. D. S. Madge, Agricultural Research Council Scholar, and B. S. Miller, Professor in the Department of Flour & Feed Milling Industries, Kansas State College, holding a National Science Foundation Senior Post-doctoral Research Fellowship, joined the department. C. G. Johnson continued his secondment to the West African Cocoa Research Institute in Ghana for the whole of the year.

H. F. Barnes obtained special promotion to the Grade of Senior Principal Scientific Officer; all his colleagues greatly appreciated this deserved recognition of his contribution to research.

During July the Station, and the Entomology Department in particular, were hosts to the Colloquium on Research Methods in Soil Zoology, organized on behalf of the Soil Zoology Committee (Biology Commission) of the International Society of Soil Science. The full brunt of the work fell on P. W. Murphy, the organizing secretary and editor, but most members of the department assisted and presented communications or demonstrations.

K. Mellanby was elected President of the Association for the Study of Animal Behaviour. J. W. Stephenson was awarded the degree of M.Sc. London University.

R. M. Dobson gave a course on " Life in the Soil " at Flatford Mill (Field Studies Council) in August. K. Mellanby gave a paper on "Acclimatization of Insects to Low Temperatures " in the symposium on " Life at Low Temperatures " at the British Association meeting in Glasgow, and a course on " Recent Advances in Biological Science " to the school for junior clergy of the Church in Wales at St. David's College, Lampeter, in September.

The new glasshouses and insectaries were built, and work is in progress to complete the installation and regulation of the heating and ventilating system. The building planned as a " potting-shed " has been adapted as a soil zoology laboratory and houses three workers. These additional facilities should increase the scope of the department considerably.

Insect Physiology and Behaviour

Work on fundamental problems relating to insect physiology and behaviour, particularly as these are affected by climatic conditions, has continued. This work is closely related to many of the investigations described in later sections of the report, and the intention is that this relationship should become closer, but at present certain lines of study are still distinct.

Further results have been obtained showing the rapidity and

importance of acclimatization to many species of insect. Acclimatization, complete in under 24 hours, affects not only the position of the cold and heat death points, but also may have a profound effect on behaviour. The importance of these effects on behaviour, rather than on survival, is receiving increasing attention, for the majority of species of insects seldom experience lethal exposures to extreme temperatures.

Effects of moisture have been studied further. Drinking by insect larvae has been shown to be important in several more species, including the European corn borer (*Pyrausta nubilalis* (Hbn.)), a serious pest of maize in North America. Water gained by drinking is important in enabling insects to survive unfavourable conditions of temperature and humidity. Work on fat metabolism also continues. (Mellanby and French.)

Insect Pests at Rothamsted

Periodic inspections of the crops at Rothamsted for insect damage have continued, and advice has been given when requested by other departments. On the whole, little serious damage from insects has been seen in 1958. The spring migration of the bean aphid was small, attacks on experimental or commercial crops of beans were light. Damage by bean weevils (*Sitona* sp.), though it occurred in most areas, was slight. Patchiness in spring wheat in one section of Delharding was thought to be due to leather-jackets (*Tipula* sp.), although no larvae could be found to confirm this diagnosis from the typical damage observed.

The oats planted on 25 March showed little frit-fly attack, though later experimental crops were heavily infested (see p. 135 below). Wheat-bulb-fly attack was insufficient to cause material losses in any of the wheat crops. (French.)

Frit-fly Investigation

Work was begun in this department in the autumn of 1957. During the winter preliminary observations on the distribution of larvae were made. In April a comparison was started on the infestation of two adjacent areas of the oat varieties Eagle and Sun II; this was done as part of a National Agricultural Advisory Service co-operative experiment, but we were able to make some additional observations. A number of small patches of oats were also planted on different parts of the farm, and the frit population was studied in them also. A comparison was made of the efficiency of different methods used for trapping adult frit flies. Grain samples from these experiments are still being examined, and the results are being analysed.

It was confirmed that frit-fly attack can stimulate tiller production in oats. An area of Sun II, sown 25 April 1958, was partly covered by terylene cages from 15 May to 16 June (while most frit flies were egg-laying); this completely protected the oats from tiller attack. Another part of the crop was sprayed with DDT twice (12 May and 22 May); this reduced the infestation to one-third. The table shows that, from 80 plants in each sample, the uninfested

plants had on an average 2 tillers, and the heavily infested sample had 4·9 per plant.

	Control	DDT sprayed	Caged
Tillers	356	292	165
Tillers attacked	139	39	0
% attack	39·1	13·4	0

(Riches, Mellanby and French.)

Insect Migration

The most notable migration reported this year was that of the Diamond-Back moth, *Plutella maculipennis*, an insect which may be a serious pest of cruciferous plants. This did not occur at Rothamsted, but many reports from the north-east coast of England and the east coast of Scotland were received, showing that thousands of millions of moths appeared about 28 June. Although some damage to crops was reported, even where no spraying of insecticides was possible this was of little importance, as the cold wet weather seemed to reduce the number of caterpillars produced by the migrants to quite small numbers. So far the exact source of this migration has not been fixed; Scandinavia was also subject to it, so Russia seems the probable place of origin of the moths.

Most regular migrants were recorded in 1958, as in 1957, in low numbers. There was a very early immigration of many species in the latter half of February, but further immigration was halted by a spell of cold and wet weather, and these species did not appear again until the beginning of May. These immigrants did not increase in numbers greatly by breeding in Britain, because of the cold weather, and it was not until a further late immigration in August and September that the Painted Lady (*Vanessa cardui*), the Red Admiral (*Vanessa atalanta*) and the Silver Y moth (*Plusia gamma*) became at all common. In the earliest migrations some of the less-common species (e.g., *Laphygma exigua*, *Heliothis peltigera*, *Plusia ni* and *Nycterosea obstipata*) were present in relatively greater numbers than usual. The migrant hawk moths, in particular the Humming-bird hawk moth (*Macroglossa stellatarum*), were to be found in only small numbers throughout the year. (French.)

Experimental Ecology of Mites Inhabiting Moss and Lichen

The mite population of various habitats is being studied, and the behaviour and physiology of the different species investigated. (Madge and Mellanby.)

Gall Midges of Economic Importance

Gall midges, either of known or of potential economic importance, show great population fluctuations. Investigations are primarily aimed at explaining these fluctuations, and in establishing more accurately the relationship between various gall midges and their host plants. This latter work has been extended during 1958 to include a biochemical examination of susceptible and resistant

varieties of wheat in relation to hessian-fly (*Mayetiola destructor*) attack. In the first instance, qualitative identifications of the amino acids, organic acids, sugars and phenolic compounds present in the tissues of various wheat varieties which range from very susceptible to totally resistant are being made. Another new line of work concerns the nature of the damage done by the midge *Contarinia tritici* to wheat grains; the effect on milling and baking quality is being studied.

The long-term study of the wheat-blossom midges, *Contarinia tritici* and *Sitodiplosis mosellana* on Broadbalk reached its 32nd consecutive year. As expected, the infestation by both species increased markedly in 1958 over the 1957 level. (*C. tritici* from 4,596 larvae per 500 ears to 14,550; *S. mosellana* from 602 to 1,969. Grain infestation increased also.) In the insectary a new record was established; one *S. mosellana* adult emerged 17 years after the larva fed and entered diapause.

Studies are being made to determine the actual field resistance of different wheat varieties to *C. tritici* and *S. mosellana*. It has been found, for instance, that though the variety Atle has been described as resistant, it is in fact quite susceptible if ear emergence coincides with midge emergence. Dates of ear emergence of winter wheats (Hybrid 46, Square Heads Master) and spring wheats (Svenno, Atle, Fylgia II) on experimental plots are being related to emergence and oviposition of midges on the open and in the insectary.

Larval descent from the wheat to the soil has been studied at Rothamsted and at Cockle Park, Durham. The date of descent varies considerably, not only from widely separated areas, but even from field to field on the farm. Thus in 1958 the descent of *C. tritici* larvae, started about 9 July on Capelle wheat on Pennell's Piece, about 20 July on Plot 8 of Broadbalk and even later on other fields at Rothamsted.

Last year *Stenodiplosis geniculati*, one of the Meadow Foxtail seed midges, was shown to be breeding on Timothy grass at Rothamsted. In 1958 National Agricultural Advisory Service entomologists have shown that it also breeds on Timothy grass in Cardigan, Merioneth, Derbyshire, Oxfordshire and Buckinghamshire.

Data are being accumulated regarding the speed at which the life cycle is completed by the hessian fly, in the open glasshouse and in the laboratory. In the open glasshouse the quickest cycle (31–33 days) was found in June and July; later the period increased (45–51 days) and no adults emerged the same year from eggs laid after the end of August, as the larvae overwinter in puparia. Transfer of these to warm conditions shows that some adults may emerge quite soon, but the response to heated-room conditions has been very variable. To try to elucidate this point, and also to provide adult material for other experiments at all times of year, the effects of controlled temperature and humidity conditions on emergence are being investigated.

The importance of the genus *Mayetiola*, in addition to the hessian fly, indicates that further study is required. A species of *Mayetiola* damaged *Poa pratensis*, and another species destroyed a field of cocksfoot. Both these grasses are grown for seed crops. A new

species, *Mayetiola schoberi*, has been described from *Poa pratensis* in Germany.

Preliminary studies of gall midges in the stubble of oats, wheat and several species of grass have shown that several species are concerned; they may be of importance in the breakdown of stubble, but their biology has not yet been worked out.

Advisory and taxonomic work has continued, and inquiries have been received from Germany, Sweden, Turkey, the U.S.A. and, through the Commonwealth Institute of Entomology, from Aden, Cyprus, India and South Africa. Close touch has been maintained with the National Agricultural Advisory Service. Several specialist workers have visited the department and consulted the Barnes collection; mention may be made of the visit from 13 to 27 March of Dr. E. Möhn of the Staatliches Museum für Naturkunde in Stuttgart. (Barnes, Arnold and Miller.)

Studies on Slugs

Weekly collections of slugs have been continued throughout the year in a Harpenden garden. The numbers and weights of those collected correspond to those in collections made by H. F. Barnes from 1941 to 1945. Particular attention has been given to the study of *Arion hortensis*, *Arion subfuscus*, *Agriolimax reticulatus*, *Milax budapestensis* and *Milax sowerbyi*. Study of the gonads of these slugs has given information about the breeding and feeding habits. (Cochrane and Barnes.)

Wheat-bulb-fly Investigations

(*Leptohylemyia Coarctata*)

Field studies

The two field experiments, begun in 1957 in commercial farms, Herkstead Hall and Fowes Farm, in Essex (*Rep. Rothamst. exp. Sta. for 1957*) have been completed. Each was planned to obtain information about the effect of different tilths on oviposition, the effect of plant and shoot density on larval survival and the effect of infestation on yield.

Egg counts made at the end of the oviposition period showed that the fallow treatments had induced different levels of infestation (*Rep. Rothamst. exp. Sta. for 1957*) and confirmed the results of an earlier experiment done at Rothamsted (*Rep. Rothamst. exp. Sta. for 1954*) which showed that a rough tilth and cultivation during the oviposition period both resulted in heavier infestations than did a smooth tilth or no cultivation.

To study the effect of plant and shoot density on larval survival each experiment was drilled at two seed rates on split plots to obtain contrasted plant and shoot densities. Estimates of plant infestation in spring showed that more larvae per unit area were found in the split plots drilled at 3 bushels/acre than in those drilled at a lower seed rate for each of the four levels of infestation studied. Soil samples taken after pupation showed corresponding differences in the numbers of pupae in the split plots.

The yield of each split plot was taken at harvest. At Herkstead

Hall a long delay in applying a spring dressing of nitrogen seriously retarded growth on some plots and vitiated the results. At Fowes Farm no effect of infestation on yield was detected, although the infestations ranged from 150,000 to 900,000 larvae/acre on the split plots sown at 3 bushels/acre and from 45,000 to 450,000/acre on the split plots sown at $\frac{2}{3}$ bushel/acre.

Effect of plant and shoot density on survival of wheat-bulb-fly larvae

1 April 1958

	Herkstead Hall		Fowes Farm	
Seed rate	3 bushels/ acre	1 bushel/ acre	3 bushels/ acre	$\frac{2}{3}$ bushel/ acre
Plants (thousands/acre)	900	360	930	314
Shoots (thousands/acre)	3,220	1,475	4,440	1,950
Infestation ratio:				
Larvae	1·6	1·0	2·8	1·0
Pupae	1·4	1·0	2·7	1·0

In practice, early sowing is recommended so that growth and tillering is well advanced by the time the wheat-bulb-fly larvae hatch. The experimental results showed that an early sown crop can withstand heavy attack without a reduction in yield. They also indicate that an early sown crop favours survival of the pest better than a late-sown one because it will have tillered more. This may mean that culture methods which reduce damage in the current year may increase the fly population and the possibility of damage in succeeding years. (Raw and Lofty.)

Field studies on emergence, survival and activity

A marking experiment was again made in a field cage on Pennell's Piece during the summer. A cage twice as large as before was used (i.e., 24 × 24 × 6 feet), and by dividing the enclosed crop into small plots, and thinning and weeding when necessary, observations were made without touching the plants or disturbing the flies. The observations gave much information on emergence, longevity, movement and individual behaviour, but the full results have yet to be analysed. (Dobson.)

The results of two experiments using marked flies to investigate movement in the field are also still being analysed. (Dobson and Long.)

Larval studies

The spring survey of larval infestation in winter wheat after fallow showed a slight rise over 1957 (428,000 larvae/acre as against 370,000 larvae/acre) on Broadbalk. On the Alternate Wheat and Fallow, however, the level fell again, to 168,000 larvae/acre. These two areas had very similar populations in 1954–56, but this experiment has reduced the area of bare land available in summer in the alternate wheat and fallow, and this reduction has coincided with a halving of the larval population. This may indicate that the width of these long, narrow plots has reached a critical value, and further work on the effects of this on the behaviour of the fly is being planned.

The experiment on the alternate wheat and fallow using seed

rates of $\frac{1}{3}$ and 3 bushels/acre has continued. This season one striking result of a non-entomological nature was the demonstration that, on this very poor soil, the young wheat sown at $\frac{1}{3}$ bushel/acre looked very much better nourished (colour, size of plant) than did that sown at the more normal rate of 3 bushels/acre. It was confirmed that the rate of larval infestation was higher in the denser sowing, but there is some evidence that the flies developed better in the thinly sown wheat. The thinly sown wheat was no more attractive to the egg-laying female than the denser areas.

Larvae are known to locate plants by chemotaxis, as they move up the increasing gradient of exudate from the growing plants. An attempt was made to " confuse " larvae by destroying this gradient. An aqueous solution of exudate was prepared from some 2,500 plants each week. This was sprayed at weekly intervals on 25 plots each of 4 sq. ft. of wheat following fallow from 3 January to 12 March. 1,700 plants were growing on the sprayed areas. Samples taken on 18 March showed 14·8 per cent more larvae in these samples than in samples from control (unsprayed) plots. This suggests that the sprayed exudate attracted larvae from outside, and that this more than offset any confusion caused by the spray. Preliminary analyses suggest that the active ingredient in the exudate is a protein or protein-like substance.

A detailed analysis of data on larvae infestation covering the last 5 years has been undertaken in collaboration with Marjory M. Morris of the Statistics Department. The incidence and distribution of some 8,900 larvae in 42,000 plants is being studied, and the results may increase our understanding of the interaction between the larva and the host plant. The results suggest that differences in " quality " between individual stems may influence the distribution and success of the infestation. This " quality " may be associated with the age of the stem. (Long.)

Aphid Ecology and Insect Dispersal

The distribution of insects in the air

Much information has been accumulated about the number of insects present at various heights in the air. Those records at high levels, from 50 to 20,000 feet, have already been treated collectively, by Johnson (*Rep. Rothamst. exp. Sta. for 1956*), and shown to produce a definite pattern of insect density in relation to height. This suggests a dependence of some insects upon physical factors for their upward, and consequent horizontal, dispersal.

At lower levels, up to 50 feet, there is also much information, collected over the last 30 years, but it is difficult to analyse because of the method of collection, which usually measures, not insect density, but the flow of insects past a point. This quantity depends as much on wind speed as on insect numbers. An attempt has now been made to collect the material together and make allowance for this error of measurement. The results suggest strongly that previous conclusions based on these records, which maintained that many species of small insect fly at specific heights, are probably due to an artifact of the sampling methods used. It also appears that, with these small insects, thrips, aphids, psocids, frit fly and even

coccinellids, the density diminishes in a fairly regular way with increase in height. This is understandable if the majority of flight occurs when the wind speed exceeds the insect's flight speed, as is probably true with such day-flying insects. The information about larger insects is more limited, and has not yet produced any conclusive results. (Taylor.)

Temperature and development

The work of relating growth in *Aphis fabae* to temperature has been started in the laboratory in order that population growth in the field may be related to temperature and hence to time (*Rep. Rothamst. exp. Sta. for 1957*). The time taken by *A. fabae* nymphs, feeding on broad beans, to develop from birth to the final moult has been measured at constant temperatures in the laboratory. It varies from more than 40 days below 8° C. to a minimum of 4·7 days at 29–30° C., and above this temperature it increases again. Humidities varying from 15 to 85 per cent (relative humidity) do not greatly affect these times, although mortality is apparently influenced by humidity.

The duration of development was also measured in a glasshouse, where the temperature fluctuated daily and reached a maximum of 31° C. and a minimum of 7° C., and where humidity also varied over a wide range. The expected time for the final moult, calculated from the results at constant temperatures, was within 5 per cent of the measured time in this preliminary trial. These measurements will be repeated with more critical temperature records to see how accurately the effect of constant and fluctuating temperatures coincide, i.e., to find out if temperature is the sole external factor affecting the rate of development of an aphid on a given host. (Taylor.)

Reproduction in Aphis fabae

The reproductive capacity of various forms of *A. fabae* has been examined under constant conditions. It seems that all spring and summer virginoparae, apterous and alate, have the capacity to generate, on the average, about ninety-five nymphs. This is independent of the host they are reared on and whether they come from the field or from a culture of many generations of virginoparae. But the ability to produce these nymphs alive depends primarily on the longevity of the parent. This in turn depends on two major factors: the reserves present in the newly matured adult and the food available during reproductive life.

The biggest factor affecting reserves is the absolute size of the aphid. In order to live to its full term of about 30 days at 20° C. an aphid must exceed a certain minimum size. This creates a strong bias against the chances of an alate completing its reproductive function even if it finds a suitable host, for the average size of field alates is well below this critical value. Aptera, on the other hand, are usually large enough to live for 30 days provided they have enough food to continue reproducing. Shortage of food does not stop the aphid reproducing, so that it might continue to live on the material available, but the aphid starves to death while reproduction continues in full spate. Autumn winged forms may not behave

in the same way, but the evidence is so far very limited. The basic reproductive potential of sexual forms has not yet been established. (Taylor and Cockbain.)

Flight studies in Aphis fabae

The nature of the reserves used during flight by *Aphis fabae*, their distribution in the body and their depletion during flight were studied in aphids flown tethered to pins in a wind tunnel under controlled conditions. Both glycogen and fat were used, the main reserves of which are in the fat body cells of the abdomen and thorax, and in the flight muscles themselves. During the initial period of flight, glycogen is used, but within a short time this reserve shows signs of depletion and the fat is then mobilized. From the first hour of flight, the total fat content decreases uniformly. After a flight lasting 6 hours the decrease in fat represents about 90 per cent of the total energy transformed.

The factors affecting the duration of tethered flights were also studied. Aphids flown in this manner can fly for several hours, the actual duration before fatigue sets in depending on temperature and the amount of initial reserves. The temperature at which cultured aphids flew longest was just above the flight threshold, i.e., 16–17° C. Presumably an increase in the rate of metabolism and a greater water loss shortened flights at higher temperatures. The duration of flight at a constant temperature is closely related to the initial fat content. During flight, water is lost by evaporation, and the total decrease in water content depends on the temperature and humidity of the air. The importance of evaporation of water from the insect's body in stopping flight is difficult to assess, however, for some fluid is directly lost by excretion during flight.

Work has also proceeded on the effect of flight fatigue on the subsequent reproduction of the flight-exhausted parent. Results indicate that large aphids, even when flown to exhaustion, can still settle on a suitable host plant, feed, reproduce and establish a colony. Mortality of the nymphs produced by flight-exhausted alates appears to be no higher than in nymphs born of parents which have flown for several minutes only as opposed to several hours.

Field studies of alighting and growth of populations were planned for this season, as well as a second experimental investigation of the effect of planting date on aphid colonization. However, there was a very poor primary migration, and an equally poor growth of populations during the summer due to climatic conditions, mainly low temperature. The complete failure of this aspect of the work was finally ensured by the drift of insecticidal spray into the experimental plot. (Cockbain.)

Earthworm Studies

Rehabilitation of marginal grassland

Observations have continued on the field experiment at Lancaster begun in 1954 to investigate the influence of earthworms on the rehabilitation of marginal grassland. Soil samples were taken in April and November to estimate numbers of earthworms and cocoons. These confirmed the result obtained in 1957 that the

plots initially treated with lime and phosphate now have much higher populations than the other plots. So far no effects of dung or artificial fertilizers applied after this initial treatment have been detected. The population of plots initially treated with lead arsenate to eliminate all worms is still very low, though the November samples showed some evidence that one species, *Eiseniella tetraedra*, was increasing in numbers on some of these plots.

In November the samples were divided and the mat and mineral soil examined separately. Few worms were found in the mineral soil, and pH determinations showed that there is still a steep gradient of pH in the soil profile. This suggests that pH may be limiting burrowing, though waterlogging and aeration may also be involved. Another dressing of lime and phosphate will be given soon, and thereafter an annual maintenance dressing of lime will be given.

Tests made on the November samples showed that about half of the worms in the mat samples were missed by hand sorting but were recovered by a washing method. Most of these worms were small, and more were missed in wet samples than in dry. To avoid this selective loss the washing method will be used in future.

Material has been collected for laboratory work on some problems of earthworm biology relating to the field experiment. (Raw and Dobson in conjunction with Mr. E. Crompton of Durham University.)

Earthworm populations in orchards

In four orchards near Wisbech which have received different manurial and fungicide treatments, J. M. Hirst estimated the survival of apple leaves between leaf fall and spring and we estimated the earthworm population. In one orchard, where 85 per cent of the leaves survived, we found few worms, in the other three, where only 2–15 per cent of the leaves survived, we estimated there were 300,000–500,000 worms/acre (*Rep. Rothamst. exp. Sta. for 1957*). Six species of worms were found and, of these, *Lumbricus terrestris* removed most leaves from the soil surface in pot experiments.

An experiment has now been started to estimate the rate at which earthworms in orchards bury leaves. Ten wire cages each 2 feet square, contained 100 apple leaves of known fresh weight and estimated dry weight, have been placed in each of seven orchards, five grass and two arable. Ten *L. terrestris* were added to two cages in each orchard. The number of leaves pulled into the soil and the decrease in dry weight of the remainder will be recorded, and the earthworm population under the cages will be estimated. (Raw and Stephenson.)

Biological studies

Effects of environmental factors, particularly temperature and soil moisture, are being investigated in the laboratory, using several species of earthworm. Changes in body-weight, cocoon production and the onset of aestivation are among the reactions being noted. These experiments are planned so that the results may show what environmental conditions are optimal, and which are, in varying degrees, unsuitable for the different types of worm. Field observations are being made to supplement the laboratory experiments.

For instance, records are being kept of surface activity of worms at night, in relation to changes of air and soil temperature.

Field experiments on worm biology have made it necessary to sample the population in the areas under consideration, so that we may know what worms are being investigated. The reliability of existing sampling techniques has therefore been reassessed. Digging and washing the soil seems to be the only reasonably accurate method. Electrical and poisoning methods bring only a small proportion, perhaps less than 10 per cent, of the worms to the surface. Some poisons (e.g., Mowrah meal, permanganate) bring these worms up in a few minutes; others (e.g., rotenone) take several days to act.

Knowledge concerning the food of earthworms is still scanty. Several species appear to feed on dung, though we do not know what part of the dung they assimilate. Preliminary experiments on cellulose digestion and the effect of earthworms on soil organic matter have been made in collaboration with N. Walker of the Soil Microbiology Department. (Gerard, Raw and Mellanby.)

Ecological Studies on the Natural Enemies of Aphids

The study of the association of the garden ant (*Lasius niger*) with the bean aphid (*Aphis fabae*), started in 1956, was continued in 1958. Experiments were made to assess the degree of protection given to *A. fabae* by the ant against attacks from the aphid's insect enemies; the effects of various predator species in reducing known populations of the aphids on bean plants were also assessed.

The results confirmed the earlier finding that the protection given by the ants against Coccinellid larvae, whether large or small species, was almost complete, so that the aphids were able to feed and reproduce unhindered; but these predators were able to destroy many of the aphids when they were not ant-attended.

The aphids were also protected from the attacks of Anthocorid bugs which, probably because of their small size, were not very effective in killing many aphids.

Syrphid larvae were able to eat very few aphids attended by ants, but quickly destroyed many aphids in the absence of ants; despite their large size, they were able to find and destroy aphids hidden in crevices on the plants which small predators like Anthocorids can also do. Chrysopid larvae were also attacked by the ants, which, however, protected aphids less completely against these predators; Chrysopid larvae can also destroy many aphids in the absence of ants.

The parasitoid wasp, *Aphidius* sp., was not attacked by ants and did in fact destroy more ant-attended aphids than aphids which were not so attended.

Field experiments confirmed the effectiveness of Syrphid larvae in killing many aphids on bean plants. These predators appear to be very efficient individually, and their importance, unlike that of Coccinellids, appears to have been underestimated, no doubt because they are not so conspicuous.

The study of the ecology of *Aphis fabae* and its control by natural enemies, started in 1956, continued in collaboration with M. J. Way

of the Insecticides Department. Many aphid eggs had overwintered on some of the spindle trees selected for special study, but many of the nymphs which emerged in February did not survive the cold weather throughout that month. Predation by Coccinellids and Anthocorids, which were very abundant, further reduced the aphid populations on spindle in the early spring. Consequently, relatively few aphids migrated and colonized spring beans in May and June, and Coccinellids and Anthocorids again took their toll. Later, in July, Syrphid larvae were especially abundant and were responsible for eliminating many colonies of the aphids on beans.

Small aphid populations continued on beans in August and September, and sufficient winged forms were produced in September and October on sugar beet and weeds like *Chenopodium* to provide a substantial build-up of aphid populations on spindle in the autumn. A detailed study of the mortality of the overwintering eggs of the aphid is in progress. (Banks.)

Biology of *Aphis Fabae*

Work on the feeding and excretion of *Aphis fabae* was resumed. By allowing the aphid nymphs to feed on bean plants made radioactive in water culture containing ^{32}P and measuring the radioactivity of the insects and their excreted honeydew, the amount of food ingested and material excreted during various times of feeding was estimated. (Banks with H. L. Nixon of Plant Pathology Department.)

Studies are in progress to determine whether there are biochemical differences in the juices of bean (*Vicia faba*) varieties, which may explain the known differences in the degree of attack of different varieties by *Aphis fabae*. Amino-acids, organic acids, sugars and phenolic compounds present in the juice extracted from both young- and old-leaf samples from resistant ("Rastatter") and susceptible ("Schlanstedter") bean plants are being investigated. (Banks, Miller and Arnold.)

The Effect of Synthetic Oestrogens on the Soil Fauna

The synthetic oestrogens hexoestrol and stilboestrol when used to fatten stock may reach the soil in the excreta of treated animals. Little is known about their breakdown in the soil or their effect on the soil fauna. At the request of the Agricultural Research Council some observations on the latter problem are being made.

At present, the results of pot experiments and field observations suggest that hexoestrol only affects the soil fauna when present in amounts which are many times greater than any likely to occur in practice. (Raw.)

Soil Fauna Associated with Raspberry Ringspot Virus

There is a strong evidence that soil organisms are concerned in the transmission of soil-borne viruses of the ringspot type. At three sites the soil fauna near infected plants was compared with that near healthy plants. At each site many more Collembola, and at one

site more Tyroglyphid mites, were found near the infected plants. The preponderance of these groups suggests a saprophytic association with the diseased plants and need not imply a direct association with the virus. (Raw, in conjunction with B. Harrison, Plant Pathology Department.)

Studies on Beetles

No biological investigations of beetles have been made during the present year, but routine identification of *Carpophilus* spp. (Nitidulidae) have continued. Specimens have been received from many parts of the world, including the Soviet Union, and in all, about 120 packages have been dealt with. Of exceptional interest was a single specimen of *Carpophilus fumatus* Boheman found in cocoa in Ghana. This species has previously been recorded only once or twice from stored produce. (Dobson.)

Population Density Studies on Insects

Earlier experiments showed that the larval population density of several species of lepidoptera strongly influenced the rate of subsequent development of the individual, and pilot experiments have been set up under constant-temperature conditions to study its mode of action. These experiments, so far, have shown that the environmental conditions, in terms of population density, during the larval state of the parents can influence the developmental pattern of the F_1 larvae. These experiments await confirmation in a second series planned for 1959.

Studies have also been started on " weight economy " during the pupal stages to explain differences observed between larval and adult stages in both solitary and crowded cultures.

A study has been completed on the morphology of the adults from both solitary and crowded larval culture, taking into consideration changes in weight during adult life. (Long.)

BEE DEPARTMENT

C. G. Butler

J. B. Free was awarded a Postdoctorate Fellowship by the National Research Council of Canada, and in September left to spend one year in the Apicultural Department, Ontario Agricultural College, Guelph. In March L. Bailey lectured in Oslo and Copenhagen at the invitation of the Beekeeping Associations of Norway and Denmark, and in August visited Prague as a guest of the Czechoslovak Academy and attended the 1st International Congress of Insect Pathology. In September C. G. Butler attended the 4th International Conference of Bee Research Workers at the University of Bologna and the 17th International Beekeeping Congress in Rome.

Members of the department have lectured at meetings of scientific societies, beekeepers' associations, etc., and have also continued to serve on various committees concerned with beekeeping, pollination, etc.

Bee Behaviour

Swarming

A method of determining, biologically, in the laboratory, the efficacy of any given substance to inhibit queenless worker honeybees from rearing queens (see *Rep. Rothamst. exp. Sta. for 1957*, p. 169) has been considerably improved, and a start has been made in determining the amount of queen substance that can be extracted from queens of various types. Preliminary results suggest that queens that have actually been superseded by their workers, and queens who have swarmed from uncrowded colonies, possess less of this substance than queens from colonies of similar size in which the workers have not reared any new queens. These results support the view that swarming is, like supersedure, initiated by a shortage of queen substance (Butler). It is, however, still uncertain why colonies sometimes replace their queens by the process of supersedure and at other times by swarming; nor do we know what causes swarming bees to leave the parental hive.

When a swarm is put into a hive a short distance away from the parental one, few, if any, of its worker bees return to the parent colony (Free), whereas if bees with a queen are taken experimentally from a colony and similarly treated, a large proportion of them return to the old position. Attempts are being made to discover whether bees in a swarm behave in this way because they have lost their memory of the old site, or know both sites and prefer the new, or have never learned the position of the old site. When individual bees were removed from a newly emerged swarm, marked and released about 40 yards away, those subsequently found were all in the colonies nearest to the point of release, and none was recovered either from the swarm or from the parent colony.

In other experiments, series of marked bees of known age were built up in colonies and, subsequently, single marked bees and parts of the colonies were moved to new positions. Among the bees in the older age groups, the proportion failing to return to the old position was far less than the proportion which would have left the hives had the colonies swarmed (see Butler, *Bee World* **21** (1940), 9–10). Thus it appears that many of the bees in a swarm do not know, or have forgotten, the position of their old hive, but are not simply the bees which, in a normal colony, would have been too young to have flown out and become orientated to the site. (Simpson.)

When the queen is removed from a newly emerged swarm the swarm cluster breaks up and the bees fly back to the parent colony. Their behaviour while doing so is similar to that when a swarm is emerging. The swarm breaks up within 10–15 minutes of the removal of the queen and so cannot be due to exhaustion of the supply of queen substance obtained by licking the queen's body and transferring honeystomach contents from bee to bee. Bees in a swarm must therefore perceive the presence of a queen by some other means—perhaps by scent or sound.

The time taken for a non-swarming colony to show signs of queenlessness was investigated by the use of a pair of observation hives so constructed that a queen (or any other bee) can be removed without disturbing the colony. The queen of one colony was removed, kept temporarily in an incubator and presented in a wire-gauze cage to both of the colonies at successive intervals of time. The bees of the queenright colony paid little attention to the queen in the cage at any time, in spite of the fact that she was a stranger. Those of the queenless colony paid little attention for several hours, but eventually became more attentive and, after 4 or 5 hours, had become decidedly hostile. When the queen was released in her own colony she was immediately attacked and " balled ", and her safe re-introduction was possible only after she had been caged in the colony for a lengthy period—in one case, 3 days. The basis of this behaviour is not clear, but it is important in relation to queen introduction, because it not only confirms previous conclusions that a queen to be replaced should not be removed until immediately before the new one is put in (see Butler & Simpson, *Bee World* **37** (1956), 105–114, 124), but also shows that introduction can sometimes only be achieved safely by periods of caging much longer than those obtainable with any existing system that allows the bees to release the queen. (Simpson.)

A peculiar type of dance, described as dorso-ventral abdominal vibration (D-VAV) (Milum, V. G., *Amer. Bee J.* **95** (1955), 97–104), is sometimes performed by worker bees with their front legs in contact with other worker bees, and during swarm preparations it is similarly performed on the queen. An attempt has been made to investigate the circumstances under which this dance is performed on workers, in the hope that it may subsequently be possible to make a similar study of its performance on the queen. The dance does not simply occur at random among the worker bees, because bees marked while doing it were more likely to be seen doing it afterwards than bees marked at random on the comb. Some bees

were seen to perform almost continuously for long periods, whereas others danced only occasionally. The minimum age at which individual bees (sixteen bees) began to perform the dance was 5 days and the mean about 10. Bees marked after being seen to dance were more likely to be seen foraging within the next 3 days than bees marked at random. Bees marked when returning from foraging for pollen were more likely to be seen dancing within the next 3 days than bees marked at random—in spite of the fact that they were out of the hive during much of the periods of observation. Ability to return to the hive when released a short distance from it (in an apiary in which other colonies were present) was at least as great among D-VAV bees as among foragers. It seems possible that the bees which perform this dance are either foragers or potential foragers, the latter probably being mostly young bees ready to forage but not yet doing so because nectar or pollen sources are few. (Simpson.)

Queen substance

The residue from an ethanol extract of queen honeybees (i.e., of queen substance), when fed in distilled water to queenless worker honeybees, can inhibit them from queen rearing (Butler & Gibbons, *J. Insect Physiol.* **2** (1958), 61–64). It has now been demonstrated that the inhibitory substance is produced in the mandibular glands of a queen and is probably distributed over her body surface, whence her workers can collect it when she grooms herself (Butler and Simpson). The contents of the mandibular glands of a queen can also inhibit ovary development in queenless worker honeybees when fed to them (Butler).

The improved biological method of determining the amount of queen substance in a given sample is being used, among other things, to determine the activity of certain fractions of the secretion of the mandibular glands of queen honeybees, being prepared by Dr. R. K. Callow and Miss N. Johnston, of the National Institute for Medical Research, with whom we are collaborating in an attempt to isolate and identify the active principle. We are greatly indebted to many beekeepers, both amateur and professional, in Britain and other countries, who have generously supplied us with hundreds of queens for this work.

Ethanol extracts of *Apis indica* queens (kindly supplied by Mr. L. A. S. Perera) have been shown to inhibit queen rearing by groups of queenless *A. mellifera* workers when fed to them.

General Research

Salivary glands

The mechanism by which the contents of a bee's mandibular glands are discharged has been elucidated. The duct of the gland is flattened and stiffened at the point of discharge at the base of the mandible. Tension on the integumentary membrane between the mandible and the hypopharyngeal plate separates the lips of the orifice and allows discharge of the secretion which is under pressure in the gland. This tension appears to be produced by lowering and

retraction of the hypopharyngeal plate by the muscle which connects it with the tentorial bridge. (Simpson.)

Temperature regulation and food consumption

Groups containing various numbers of worker bees (10–200) were kept at given temperatures between 0° and 40° C. The temperature at which each group maintained itself and the amount of sucrose syrup of known concentration and water it consumed were measured at intervals. The percentage of bees in each group that were clustering together, and the mortality rate, were also determined.

With environmental temperatures between 25° and 35° C. the death-rate was low and similar in groups of different sizes. At 40° C. relatively fewer of the bees in groups of 200 survived than those in smaller groups. Below 25° C. the more bees in a group, the lower was the mortality rate. Groups of 50, 100 and 200 bees survived 24 hours or more at 10° C., and sometimes did so at 5° C.

At environmental temperatures up to 30° C. the bees forming a group maintained a temperature higher than that of the environment. The temperature of a group increased with that of the environment, and the lower the latter, the more it differed from that of the group. The larger a group, the higher its temperature was maintained above that of the environment. The difference between the temperatures of larger and smaller groups decreased with increase of environmental temperature until, at 35° and 40° C., all the groups were maintaining approximately the same temperature, which was either that of the environment or slightly less.

With environmental temperatures between 20° and 40° C. the percentage of bees clustering increased with the size of the group; the bees in groups of ten and twenty-five scarcely clustering at all. It is clear, therefore, that at this temperature range clustering does not take place in response to low temperature but results from mutual attraction. The more bees forming a cluster, the higher is the percentage of the available bees that joins it. However, at 15° C. 70 per cent or more of the bees clustered together irrespective of the size of the group, and at 10° C. nearly all the bees in each group were clustering.

The food consumption of the bees increased as the temperature of the environment fell, irrespective of the size of the group to which they belonged, and, consequently, their rate of metabolism and heat production rose. Little water was drunk at environmental temperatures of 30° C. and lower, but at 35° and 40° C. much was used. Such water consumption could have been due to the bees evaporating water by exposing it to the atmosphere, as the bees of colonies will do at high temperatures, or may, perhaps, have been associated with a high rate of water loss from their bodies at such high temperatures. (Free and Spencer-Booth.)

Longevity of workers

Groups of marked worker bees were introduced into each of four colonies at weekly intervals between March and October 1957 and their longevity determined. Although this varied considerably in consecutive weeks, the mean monthly value diminished steadily

from March to June, and then increased slightly during July; the weekly death-rate of bees of all ages was greater in midsummer than at any other time. Bees reared in March had a mean life of just over 5 weeks, those reared in June lived only about 4 weeks. The maximum ages attained by bees reared in each month were: March, 67 days; April, 60 days; May, June, July, 53 days.

Some of the bees reared in August and September survived until late May of the following year, and a few that emerged in the first week of October survived until the following June. No relationship was found between the age of the bees going into winter and their chance of survival until the following spring; neither was the subsequent death-rate of bees during spring and early summer in accordance with their age.

There were marked variations in the longevity of the worker bees of the different colonies both in summer and winter. (Free and Spencer-Booth.)

Observations on Apis indica

Mr. L. A. S. Perera, who is visiting the department for a year in connection with the Colombo Plan, kindly brought two colonies of *Apis indica* with him from Ceylon. These colonies, carried in the luggage hold of the plane (i.e., without heating or special ventilation), arrived in very good condition.

An attempt was made to hybridize this species with *A. mellifera* by inseminating, instrumentally, six *A. mellifera* queens with semen from *A. indica* drones. Unfortunately, great difficulty was experienced in extracting sufficient semen from the drones to give large inseminations. Although on subsequent examination the spermatheca of one of these queens was found to contain a few living spermatozoa, none produced worker brood. It is, therefore, still uncertain whether hybrids between these species can be produced.

An attempt was also made to get an *A. mellifera* colony to rear *A. indica* queens in artificial queen-cell cups, but the larvae transferred were not accepted by the host colony.

Successful natural mating of an *A. indica* queen, presumably with one or more drones of the same species (the offspring showing no signs of being hybrids), took place when one of the *A. indica* colonies became queenless and reared a new queen, in spite of the fact that drones were few and all in the other colony.

An interesting difference in the behaviour of workers of *A. indica* and of *A. mellifera* was noted. When ventilation-fanning, the former do so with their heads facing out of the entrance, thus directing an air stream into the nest and not out of it as *A. mellifera* workers do. Communicative-fanning with the scent glands exposed does not differ greatly in the two species.

Pollination

Recent observations of honeybees working on red clover flowers showed that the great majority without pollen in their pollen-baskets were collecting nectar by "robbing" the flowers and thus not pollinating, whereas nearly all the bees with pollen-loads were entering the flowers in the orthodox manner and, presumably,

pollinating them. Dissection showed that many of these latter bees had little nectar in their honeystomachs. It is clear, therefore, that honeybees will visit red clover flowers to collect pollen only, and that bees gathering nectar only from this crop are often useless as pollinators. Similarly, bees gathering pollen from apple flowers are more valuable pollinators than those collecting nectar, many of which fail to touch the anthers. Therefore, for pollination of red clover and apple flowers, pollen-gathering honeybees are more important than nectar-gatherers.

A number of workers claim to have significantly increased the number of honeybees foraging on selected crops, such as red clover, with a resultant increase in seed set, by feeding with colonies with sucrose syrup in which flowers of the crop were soaked for several hours and which contained fresh blossoms that the bees touched while drinking. The data published were not altogether satisfactory, and it seemed possible that the " directing " technique was merely increasing the number of bees seeking nectar, but not pollen, from the selected crop. As this would not increase pollination, further controlled experiments were made. The percentage of pollen of the crop concerned in the total amount of pollen of all kinds collected by bees of the " directed " colonies was compared with that collected by the foragers of control colonies fed with unscented syrup of the same concentration. The results do not indicate that " directed " colonies collected any more pollen from the experimental crops than the control colonies, so that in the present state of knowledge growers seem ill advised to try to increase the pollination of their crops by this " scent-directing " technique.

Attempts are being made to discover a satisfactory method of increasing the proportion of pollen-gathering foragers of colonies for purposes of pollination. (Free.)

Bee Diseases

Nosema disease

Of all colonies at Rothamsted, 45 per cent were found to be infected with *Nosema apis* in the spring of 1958; an apparent, but non-significant, increase since 1957. In 1957 all twelve colonies in one apiary, which were heavily infected, were transferred to combs that had been fumigated with the vapour of acetic acid, and their number was increased to twenty by subdivision. In 1958 infection was only found in five of the twenty colonies in this apiary. This was the only significant decrease of infection in any apiary since 1957. Three out of fourteen colonies in another apiary were found infected in 1957, and each colony was examined twice each month, for other experimental purposes, from September 1957 to April 1958, by which time four colonies had died and all of the remaining ten were infected. This was the only significant increase of infection in any one apiary since 1957, and was probably caused by the excessive manipulation of these colonies during the winter. However, there is also a tendency for infection to increase in colonies handled a lot during the summer. When colonies are handled, some infected bees are undoubtedly crushed, and healthy bees may become infected from licking the remains; furthermore, handling

may cause infected bees to defaecate, and this can be a potent source of infection. Bees of colonies handled in winter and spring were often seen to void excrement on the combs. (Bailey.)

Acarine disease

All colonies were examined for infection with *Acarapis woodi* in autumn 1957. This completed a series of field observations that has given information for the first time of the relationship of the type of season to incidence of infection in colonies that are not treated for their infection. During 1955, a year of good nectar-flows, infection fell abruptly; in 1956, a year of virtually no nectar-flow, it rose again; and in 1957, an average year, infection remained steady. (Bailey.)

Mortality of colonies during the winter of 1957–58 showed virtually the same relation to degree of infection as that in previous winters: the minority of colonies with over 30 per cent of their bees infected were more likely to die than the remainder; all (eight) died with over 60 per cent infection. (Bailey.)

European Foul Brood disease

An improved method of isolating *Streptococcus pluton* has been developed. The contents of the mid-guts of diseased larvae are smeared on to microscope slides and allowed to dry. Most, usually all, of the bacteria associated with infection, except *S. pluton*, die in these smears after a few days; but *S. pluton* remains viable in such dry smears for at least 15 months. Cultures prepared from dried smears, made on the special medium developed for *S. pluton*, give many more colonies of this organism than do inocula of similar size from fresh material.

Growth of *S. pluton* is completely inhibited *in vitro* by penicillin G (concentration 10^{-7}–10^{-9}); terramycin (10^{-5}–10^{-7}) and streptomycin (10^{-4}–10^{-6}). Small-scale field trials with terramycin have confirmed its ability to suppress visible signs of this disease, but the growth of *S. pluton* in heavily infected colonies was not entirely eliminated by treatment with this antibiotic. The walls of those cells which contained pupae that had developed from infected larvae became smeared with living *S. pluton*. This is a normal occurrence in untreated infected colonies, and seems likely to be the principal method by which *S. pluton* is transmitted; infected larvae which survive void the bacteria with their faeces at the time of pupation.

S. pluton, in dry smears, has been found to be extremely sensitive to fumigation by the vapour of formaldehyde or acetic acid at room temperature. No growth *in vitro* was obtained after exposure of smears to the fumes for between 5 and 15 minutes. Although comb fumigation is unlikely to provide a method of treating infected colonies, it may prove valuable for the treatment of empty combs and equipment suspected to be contaminated.

The distribution of *Bacterium eurydice*, which seems to cause visible signs of disease when superimposed on infection by *S. pluton*, is not confined to colonies with European Foul Brood disease. A survey, made with the assistance of members of the Bee Research Association, has shown it to occur in Britain and Northern Ireland in regions where European Foul Brood has rarely, if ever, been found.

Three distinct types of *B. eurydice* have been identified. One grows very feebly *in vitro* as an anaerobe, and most adult and larval bees are infected with it at all times. The other two varieties are facultative anaerobes, grow vigorously *in vitro*, and occur in most adult and larval bees in summer, but they are difficult to find in winter.

B. eurydice grows well in a pollen extract prepared by soaking 1 part by weight of pollen, trapped from pollen-gathering bees on their return to the hive or taken from the comb, in 9 parts of distilled water. The suspension is sterilized by Seitz-filtration. Although it is an excellent medium for *B. eurydice*, it does not support or influence growth of *S. pluton*. (Bailey.)

STATISTICS DEPARTMENT

F. YATES

M. H. Westmacott left to take a post with Shell-Mex and B.P. Ltd. New appointments were: A. J. Vernon, from the Department of Agriculture, Nigeria, and Beryl Turner from Bedford College, London. S. F. Buck is in the Department on a two-year Agricultural Research Council scholarship. N. E. G. Gilbert has been seconded part-time from the John Innes Horticultural Institution for a further year to continue his co-operation with the Animal Breeding Research Organisation. Ten temporary workers were accommodated during the year, seven of them from overseas.

Yates spent two months with the Indian Council of Agricultural Research on a United Nations Food and Agriculture Organization assignment (12.3). He also attended a Study Group on Immunological and Haematological Surveys in Geneva at the invitation of the World Health Organization. Healy attended the Fourth International Conference of the Biometric Society at Ottawa. Church attended an O.E.E.C. Conference in Paris on the optimum use of fertilizers (12.1), and Leech the Deuxième Journée Biométrique of the Belgian Region of the Biometric Society. Lipton attended the International Congress of Mathematicians in Edinburgh in August (12.16). Patterson returned in April from a six-months visit to the Institute of Statistics, North Carolina.

Lessells returned to work in May after recovering from a severe attack of poliomyelitis.

The Electronic Computer

Steady progress has been made in the use of the electronic computer, and the volume and range of computations done on it have increased. The machine continues to be reliable, but the peripheral equipment gives trouble.

Two useful modifications were made to the machine. The first is the addition of a further three immediate-access registers, on the lines indicated in last year's annual report. The second is an arrangement whereby a set of n numbers located in successive addresses on a track can be added in n word-times (n less than or equal to 128). Previously in the 401, as in other computers in which data are stored on a drum or disc, approximately n revolutions ($= n \times 128$ word times) have been required for this operation. (A word time = 0·1 msec.) This modification also enables the subtotal of a selection from up to 34 numbers located in successive addresses to be formed in 34 or less word times, the actual selection being determined by the pattern of ones and zeros contained in a word set in one of the registers. This latter facility has proved to be of value in forming the various sub-totals required in some types of factorial experiment. It has, for example, been used in the analysis of the Bihar series of $3 \times 3 \times 3$ trials referred to below.

Using this modification, the actual computing time required for the analysis of a single $3 \times 3 \times 3$ trial, including the computation of the main effects for each block separately, is 5 seconds, in contrast to approximately 1 minute taken by our standard $3 \times 3 \times 3$ programme. Three further by-products of this modification may also be noted: it is now possible to store links in a register and obey them directly; it is much easier to count the number of ones in a word or part of a word; and the logical OR of two words can be derived quite simply.

A further small modification displays on indicator lights the number of the relay track (track 7) in circuit.

Our experience with the special-quality valves has been followed up by detailed examination by the manufacturers. They now recommend a simple and less-stringent test than the one we had been using. We propose to prolong the life of these valves by adopting the revised standard unless we find evidence of machine failure.

Progress with the installation of a magnetic-tape unit has been disappointingly slow, partly owing to the demands of routine and other maintenance, but more especially because of maintenance and design troubles with the equipment. The main hold-up now is the poor quality of signal which is being recovered, and we await the result of an experiment being run with this type of unit at the Cambridge Mathematical Laboratory on an out-of-contact head. We have now reached the stage where magnetic-tape equipment is urgently required, and unless there appears to be good prospect of getting the present unit functioning soon, the question of getting some other type of unit will have to be considered.

The Ferranti tape readers have not been as reliable as we should like. The checked code employed usually detects reader errors before any damage can be done, but occasional duplicate readings of single characters have been reported. It is proposed to reconsider the present circuit design to see whether running conditions can be improved.

The Hollerith reader was used more this year. The high-speed relays have continued to give trouble, probably because the low pulsed currents are passed across the points. Trials are being made with a new type of relay designed to deal with the small currents involved.

The tape-to-card equipment delivered in January 1958 has not yet been much used. From our present experience we can hope for about the same standard of reliability as in the other punched-card equipment installed.

We also obtained one of the complete Creed verifier systems, but this has proved to be disappointingly unreliable. A local modification was made to give warning of a faulty condition on the machine and thus help the operator, but eventually Creeds called in all the verifiers they had produced to modify the verifier keyboard. Our equipment was only returned in December, so that we cannot comment on the reliability of the modified equipment. It is quite clear, however, that they have increased the keyboard spring tensions. Measurements show that the verifier keyboard now requires 1·5 lb. pressure to operate a key, which is about three times the pressure of a normal keyboard.

The use of mark-sensed punched cards (whereby the punching is done mechanically from pencil markings on the card) was tested, but it seems doubtful whether this system will be of great value for recording much of the experimental and survey data that require machine processing.

Table 1 records machine operation over the last 2 years, and shows the machine worked more hours in 1958 than in 1957; the percentage of overtime beyond normal laboratory hours in 1958 was 45 per cent and 33 per cent in 1957. Production time has increased by 28 per cent, compared with an increase of 9 per cent in the total time run.

TABLE 1

Record of machine operation for 1957 and 1958

	Hours		Percentage	
	1957	1958	1957	1958
System modification ...	16	69	0·6	2·4
Scheduled maintenance ...	324	398	12·4	13·9
Unscheduled maintenance:				
Computer	163	65	8·0	3·7
Peripheral	47	42		
Programme checking ...	467	382	17·8	13·3
Programme tape preparation	126	101	4·8	3·5
Production runs	1,305	1,676	49·8	58·4
Abortive efforts:				
Computer	34	39	2·3	3·1
Peripheral	25	49		
Idle time	115	48	4·4	1·7
Total	2,622	2,869	100·1	100·0
Normal laboratory hours ...	1,977	1,977		
Percentage overtime ...	32·6%	45·1%		

Several new programmes were prepared, and some of the existing programmes amended, clarified and standardized; but much further work of this nature is still required (12.2, 12.22). (Yates, Rees, Healy, Leech, Lipton, Gower, Simpson and Chedzoy.)

Experimental design and analysis

The 6 years' results of the modified Rothamsted three-course rotation experiment on the use of straw and fertilizers were examined and briefly summarized on p. 167. The results of the whole experiment will shortly be published.

The examination of the National Agricultural Advisory Services' dairy heifer rearing experiments has been completed (Westmacott 12.21), and the results of various long-term experiments on the N.A.A.S. Experimental Husbandry Farms are being examined (Patterson). During his stay at the Institute of Statistics, North Carolina, Patterson worked on extra-period change-over designs in collaboration with Professor H. L. Lucas (12.18), and is preparing a bulletin with him covering the whole subject of change-over designs.

The survey on the effect of farmyard manure on fertilizer responses has been completed (12.4), and two reports on the correlation of soil analyses with response of potatoes to fertilizers have been prepared for the N.A.A.S. (12.25). (Boyd.)

A summary of the N.A.A.S. and National Institute of Agri-

cultural Botany 1955–57 series of variety trials which included nitrogen as an additional factor has also been made (12.24). (Boyd and Lessells.)

With Dr. J. Cooper of the Glasshouse Crops Research Institute a study of the effect of heating and lighting variation on the ripening of tomatoes was started. (Gower.)

The electronic computer has continued to be successfully used in the analysis of experiments. The programmes were extended to handle general factorial experiments and certain lattice designs. The additional speed with which the analyses of experiments can be completed is particularly appreciated by the National Agricultural Advisory Service. We have this year been able to summarize several series of N.A.A.S. experiments covering several centres and seasons.

Table 2 shows the increase in the number of experiments analysed since the introduction of the electronic computer. There was a further increase in 1958 of one-third in the number of experiments and one-quarter in the number of variates analysed on the computer. Some of the experiments analysed in the past year have been exceptionally large.

TABLE 2

Numbers of replicated experiments analysed in the Department

	Number of experiments: By hand	On computer	Total	Number of variates on computer
1934	115	—	115	—
1951	437	—	437	—
1955	384	419	803	834
1956	181	683	864	1,701
1957	98	1,253	1,351	5,041
1958	182	1,664	1,846	6,260

An interesting test of the use of the computer in summarizing the results of a set of co-operative fertilizer trials was done on a set of 230 $3 \times 3 \times 3$ trials (each in 3 blocks of 9 plots) on rice on cultivators' fields in the State of Bihar, India. In these trials each of the blocks of a trial was on a separate field in a village. In the first stage of the analysis, therefore, the responses were calculated for each block separately, in addition to estimates of error and of interactions for each set of three blocks; in the second stage the variability of the responses to each of the factors within and between villages, etc., and their association with soil type and irrigation, were examined by means of a set of analyses of variance. The programming of the analysis took considerably longer than was expected, but the machine work is now nearly completed. The experience gained should prove valuable in the analysis of many such co-operative trials, which are now beginning to be much used in countries where little is known of fertilizer requirements; but the amount of numerical work involved, particularly when such trials are of the factorial type, is very considerable, and there seems a clear case for evolving methods for analysing results of this type on electronic computers. (Lipton and Yates.)

Surveys

A survey of maincrop potato growing was undertaken in co-operation with the National Institute for Agricultural Engineering and the Potato Marketing Board. This covers some 3,000 fields on 1,000 farms in Great Britain, and is on similar lines to the 1948 survey. The field work is now complete and the analysis is in progress.

The remaining twenty-three districts covered by the 1957 Survey of Fertilizer Practice have been analysed and reported on (12.23). A further twenty-one districts in England and Wales have been surveyed by the N.A.A.S. and the Fertiliser Manufacturers' Association in 1958, and the results are being analysed as they are received (Church and Hills). The electronic computer has also been used to analyse data from the Scottish surveys of fertilizer practice which are run by the Scottish agricultural colleges in conjunction with the Agricultural Research Council Unit of Statistics, Aberdeen.

The field work of the first national survey of disease in dairy cows is now nearly complete, and the analysis is being planned. Most of the work will be done on the electronic computer, using both tape and card input facilities. The analysis of a number of pilot and small-scale surveys of animal diseases is now almost complete (Leech), and the second survey of losses in breeding ewes in Yorkshire and Lancashire is finished (12.14). (Leech and Sellers.)

H. R. Simpson has done excellent work in programming most of the survey analyses undertaken on the computer. In the light of experience gained during 1958 we hope to make further progress in the extension and generalization of our programmes during the coming year, particularly in the direction of simplifying and speeding up the examination of supplementary questions suggested by the results of the main analyses.

So much survey analysis has had to be handled that the survey computing staff was overloaded, which has unfortunately resulted in delays in the reporting of some pilot surveys on the manuring of fruit and vegetables that are unsuitable for machine analysis.

In addition to the surveys mentioned above, advice has also been given in the design and analysis of other small-scale surveys. Church completed a report to the Government of Ethiopia on his survey work there (12.5).

Entomology

The effect of sterilized males on a tsetse population, in collaboration with Mr. W. H. Potts of the Tsetse Committee, has been completed. At the request of Mr. Yeo of the Colonial Pesticides Research Unit, Tanganyika, the effect of repeated insecticidal applications on a tsetse population has been studied (12.26). (Simpson.)

Marjory G. Morris has continued her co-operation with R. M. Dobson of the Entomology Department. (See above, p. 138.)

General work was continued for the N.A.A.S. entomologists and a note prepared on soil sampling for cereal-root eelworm (12.6). (Church.)

Genetics

Collaboration with Dr. E. C. R. Reeve of the Institute of Animal Genetics, Edinburgh, on the effect of inbreeding has continued (12.19). (Gower.)

Work has been done on tabulation of certain distributions required when there is selection for a variate subject to errors of measurement, for Dr. D. J. Finney and Mr. R. N. Curnow of the A.R.C. Unit of Statistics, Aberdeen (Lipton and Gower). A preliminary account of some of the results has been given at the Biometric Conference in Brussels, September 1958.

A large set of data from Danish artificial insemination centres was analysed for W. P. Jaffe of Bristol University, to discover whether there was evidence that fertility in bulls is heritable. The ratio of the mean squares between and within sires was so large that the usual additive model led to a negative environmental component. Data on the fertilities of the sires to supplement the present analysis are now being sought. Another large set of data on the characteristics of bull semen examined by the Ministry of Agriculture in connection with the approval of animals for use at artificial insemination centres has been examined for P. G. Millar of Weybridge, who is preparing a report. (Leech.)

Much work on the electronic computer has also been done for the Animal Breeding Research Organization, Edinburgh. (Gilbert.)

Advice and computing assistance has been given in the estimation of gene frequencies of β-globulin polymorphism for Mr. G. C. Ashton of the Animal Health Trust (Ashton, G. C., *Nature, Lond.*, **182** (1958), 370). (Gower.)

Colonial Work

Vernon has been in charge of our advisory work for Commonwealth workers since Westmacott left. The electronic computer is being increasingly used to analyse experimental results from Commonwealth countries. Seven Commonwealth workers have stayed in the department for varying periods.

Other Work

Of many miscellaneous problems from various research institutes dealt with by members of the department, most of which have involved the use of the computer, the following may be mentioned:

1. Work for Dr. P. H. Leslie of the Bureau of Animal Population, Oxford, on population dynamics with two competing species has been completed (12.15). A similar problem concerning the population interaction of predator and prey is now being investigated. It is hoped to do further work of this sort on the Mercury electronic computer at Oxford when this is installed. (Gower.)

2. Work on factor analysis and multivariate techniques (Healy).

3. Analysis of experiments on growth rate (Healy and Leech, 12.13).

4. Fitting of exponential and other curves (Patterson (12.17) and Lipton).

5. A numerical study of some contagious diseases relevant to epidemics, in collaboration with Dr. C. C. Spicer of the Central Public Health Laboratory (Lipton, 12.20).

6. Various medical and human growth studies (Healy, 12.9, 12.10, 12.12).

7. An investigation into double iterative methods for evaluating inverse powers of numbers (Gower, 12.7).

Work on the Cattle Efficiency Project of the Agricultural Research Council has been temporarily stopped. The work completed showed that the prediction equation originally used was not satisfactory.

FIELD EXPERIMENTS SECTION

The field experiments at Rothamsted and Woburn are controlled by the Plot Committee consisting of the following members of the staff: F. Yates (Chairman), H. V. Garner (Secretary), F. C. Bawden, G. W. Cooke, P. H. Gregory, J. R. Moffatt, C. A. Thorold, R. G. Warren and D. J. Watson.

Table 1 shows the total number of large plots on the two farms and how they were distributed between different crops and experiments of different durations. In addition, there were many micro-

TABLE 1

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted	230	153	53	—	436
Woburn	—	—	—	—	—
Long-period experiments:					
Rothamsted	277	270	243	96	886
Woburn	157	250	55	12	474
Annual experiments:					
Rothamsted	724	166	160	—	1,050
Woburn	366	—	72	—	438
Total	1,754	839	583	108	3,284

plots. The increased number of cereal plots and grass plots was more than offset by a decreased number of root plots.

The characteristics of the season are detailed in the report on the Farms; only the main features are mentioned here as a background to the account of the field experiments. The year 1958 will long be remembered for its dull, wet summer. Every month from April to November was below the average in sunshine, and the period June to September had over 4 inches more rain than usual. Conditions for hay-making were particularly bad: fortunately most of the herbage experiments, except for Park Grass, are now weighed green and sampled for dry matter. June had 4·7 inches of rain and a deficiency of over 60 hours of sunshine; singling and hoeing were hindered, and barley on the heavily manured plots began to lodge by the end of the month. July had slightly less than the average rainfall, but 18 wet days, dull weather and lack of drying winds left the land generally wet. Weeds grew fast and conditions so favoured the spread of potato blight that spraying was begun in the middle of the month. The weather became much worse in August, which rivalled June in lack of sunshine. There was much lodging: in an experiment in which the factors concerned in lodging were being studied, all plots regardless of treatment went down. The corn harvest started in the last week of August, and everything had to be dried. When work was held up by bad weather an early start was made with potato lifting, which continued under fairly good conditions till the end of September. Despite blight, yields of Majestic were only slightly below average, and there was little

tuber infection. Further rain in the first week of October made it necessary to leave the potato experiments and transfer to Barnfield mangolds, which had done particularly well in the wet summer. Autumn ploughing and cultivations for wheat and beans went on whenever possible; but with no night frosts, little drying wind and persistent showery weather the seedbeds for the early sown experiments were very poor. November had 0·34 inches less than the average rainfall, but frequent fogs, heavy dews and no drying winds made surface conditions worse and the few experimental plots of wheat and beans sown were drilled with great difficulty. Commercial potatoes came up very badly indeed, and lifting was not completed by the end of the month. A slight improvement in early December enabled most of Broadbalk (except the dunged plot) to be drilled on the 9th in the worst seedbed for many years. By mid-month water was standing in hollows all over the farm.

Notes on the Experiments

On the classical experiments the main point of note was the use of the combine-harvester on Hoosfield barley for the first time. The square plots on this field are less convenient for combining than the long, narrow strips on Broadbalk, and there is more variation within plots. Operations in 1958 were therefore preliminary, and on the more variable plots several combine cuts were taken and weighed individually. This year the effect of the long struggle against wild oats (*Avena fatua*) was unmistakable. The small amount of weed that appeared was easily hand-pulled during the summer. Unfortunately coltsfoot (*Tussilago farfara*) was now increasing on some of the plots to such a degree that a special programme of herbicides will be tried. The first step was to spray the stubble with MCPA after harvest.

Broadbalk was drilled on a rather rough seedbed on 20 November. The winter was wet but not particularly cold. On 13 December very heavy rain left water standing in furrows and on the lower parts of the field, and most of the drains ran strongly. The crop looked well until it became ragged and twisted in the August rains, but only the heavily manured plots were badly lodged. The continuous wheat section nearest the farm, carrying its seventh crop, was sprayed with CMPP. The kill of weeds was very good, heavy infestations of vetch and buttercup being controlled on several plots. On these plots, particularly those low in nitrogen, spraying improved the growth of the crop so markedly that they were taller and greener than the corresponding plots on the adjoining unsprayed section which had been fallowed only 2 years before. This striking effect is being studied in the Botany Department. The amount of chaff and small straw not picked up by the baler, and therefore left on the plots after combine-harvesting, was measured on certain plots; the figures are given in another section of this report.

The eighty-seventh crop on Barnfield was drilled in a very good seedbed on 7 May and gave a full plant with unusually high yields on the better-treated plots.

The original plots of Agdell field were cropped with Italian ryegrass generously treated with nitrogenous fertilizer to measure the

uptake of phosphorus and potassium left in the soil from the former long-period treatments.

For the second year the East end of the Exhaustion Land was drilled with six different crops to measure residual effects of the former phosphorus and potassium treatments against direct additions of these nutrients. The fresh land required for these experiments was provided by the uncropped headlands of 1957. The usual strips of nitrogen-treated barley occupied the West end of the field, and were combine-harvested for the first time.

Long-period experiments

Two methods have been employed in the Rothamsted ley–arable experiments to estimate the output of grazing land: dry matter calculated from the live-weight increases and grazing days of sheep, and dry matter estimated by sampling cuts taken at the beginning of every grazing period. Figures obtained by these two methods over an 8-year period were inconsistent, and as the weighing of sheep was difficult and time-consuming, the weighings were discontinued and the yield estimate is now made from the pasture cuts only. The reseeded grass established 6–8 years ago showed signs of deterioration, particularly on Fosters but also to a lesser extent on Highfield. Mr. J. O. Green of the Grassland Research Institute examined all the grass plots in winter 1957 and reported that the reseeded plots need not be ploughed up and resown, but could be upgraded by taking an early silage cut in alternate years. The new management, which was extended to the old permanent grass plots on Highfield also, was therefore: first year early silage cut followed by sheep grazing for the rest of the season, second year sheep grazing only. Cutting for hay, formerly carried out once in 6 years, was stopped.

The three-course rotation experiment, modified in 1952 to study more closely the effect of straw on crop yield, has now been discontinued. The results for the period 1953–58 are summarized by H. D. Patterson in this report on pp. 167–171 below.

Annual Experiments

A series of fourteen experiments testing levels and times of application of " Nitro-Chalk " to spring wheat and barley was made on both farms from 1955 to 1958. The rates of application tested were 0, 0·3, 0·6 and 0·9 cwt. N/acre in all experiments except for barley at Rothamsted, where because of the risk of serious lodging with the higher dressings the levels were 0, 0·23, 0·46, 0·69 cwt. N. Times of application for each level were: (i) all in seedbed; (ii) all as early top dressing; (iii) all as late top dressing; (iv) half in seedbed, half early; (v) half in seedbed, half late; (vi) half early, half late; (vii) one-third of the dressing at each time of application. Table 2 shows that there were very good responses to nitrogen up to 0·6 cwt. N, but the extra increase for the third 0·3 cwt. N was profitable only at Woburn.

Table 3 shows the effects of time of application.

At Rothamsted the method of application made very little difference on either crop. At Woburn late top dressing for wheat was

inefficient, and seedbed application for barley was less effective than early top dressing. These statements apply not only to the averages given above but to all the individual experiments. In

TABLE 2

Rothamsted and Woburn 1955–58

Spring Wheat and Barley

Responses to successive doses of " Nitro-Chalk " cwt./acre

(Averaging all times of application)

	No nitrogen	Successive increases N_1–N_0	N_2–N_1	N_3–N_2	Total increase
Spring wheat:					
Rothamsted	23·0	+ 6·0	+2·2	+0·8	+ 9·0
Woburn	13·2	+ 8·8	+4·8	+1·2	+14·8
Barley:					
Rothamsted	30·8	+ 4·7	+3·5	+0·8	+ 9·0
Woburn	17·5	+10·3	+6·0	+2·9	+19·2

three out of the four series, seedbed applications were as good as any other method, and the extra labour required for divided dressings was not justified; indeed, in three out of the four series the best single dressing outyielded all the divided dressings.

TABLE 3

Rothamsted and Woburn 1955–58

Spring Wheat and Barley

Effect of time of application of " Nitro-Chalk ", cwt./acre

(Mean of all rates of application)

	Seed bed (S)	Early (E) top dressing	Late (L) top dressing	½ (SE)	½ (SL)	½ (EL)	½ (SEL)	Mean of all divided dressings
Spring wheat:								
Rothamsted ...	31·6	30·8	29·8	30·0	31·4	30·0	31·0	30·6
Woburn ...	27·6	24·2	23·2	26·6	25·4	24·7	26·6	25·8
Barley:								
Rothamsted ...	37·9	37·9	38·0	38·1	38·2	38·2	38·2	38·2
Woburn ...	31·5	33·9	32·3	32·1	32·3	32·4	33·7	32·6

THE USE OF COMBINE-HARVESTERS FOR CEREAL EXPERIMENTS

Harvesting cereal plots by combine was a major advance in field technique, for it meant corn crops could now be studied not only at experimental stations but also on ordinary farms. One of the first to develop the new method was Mr. H. W. Gardner, then at the Hertfordshire Institute of Agriculture, who used tractor-drawn combines on commercial farms in 1940, and turned to the much more convenient forward-cut, self-propelled machines in 1941. Rothamsted had been well staffed and equipped for cutting, storing and threshing small plots since 1925, so there was no immediate need to change, particularly as the small square plots used in the earlier replicated and long-period experiments were not particularly convenient for combine-harvesting. Combine-harvesting of the Rothamsted plots was initiated by J. R. Moffatt, who also worked out and tested methods to suit our special conditions.

A small tractor-drawn combine, tested on the non-experimental fields in 1948, proved unsuitable for the type of plot then being used. In 1952, however, a forward-cut, self-propelled machine became available, and more elaborate comparisons between the old and new methods were started and continued for 3 years. The mean yields recorded by the two methods sometimes differed by over 10 per cent, but on average of all the results considered the differences were small. For wheat the combine yields were 0·6 cwt./acre below the binder yields, but for barley the combine gave 0·8 cwt. grain more than the binder. The difference between the yields obtained by the two methods of harvesting was not affected by differences in the rates of application of nitrogenous fertilizer. Unexpectedly the combine-harvester gave lower yields than the binder in experiments where the crop was lodged at harvest, though in standing crops the yields from the combine-harvested plots were higher than from the binder plots.

In the meantime some practical problems in operating the combine for plot work in the field, including the determination of straw yields, were solved.

The nearly square plots were replaced where possible by long, narrow ones, so that a single combine cut takes the full plot area except for the guard rows. A new drilling technique was introduced by which a single blank row is left each side of the combine cut. This greatly facilitates harvesting, especially when the crops are lodged. A standard running time, varying with the crop, is allowed between plots so that the small amount of grain carried over from plot to plot remains constant. Straw yields, as a rule, are of little interest, and are taken only when needed for some special purpose.

Combine-harvesting has greatly increased the scope of the annual experiments on cereals on both farms. In 1952, the last year under the old system, there were about 450 annual plots at Rothamsted and 8 at Woburn. In 1958 the figures were 724 and 366 respectively.

The effect of the combine on the precision of cereal experiments is of the greatest importance. A survey of the earlier Rothamsted experiments over the period 1925–38 showed that cereals in ran-

TABLE 4

Cereal Experiments Rothamsted and Woburn 1939–58

Standard errors, cwt./acre and per cent of mean

	Binder			Combine		
	Number of experiments	S.E., cwt.	S.E., %	Number of experiments	S.E., cwt.	S.E. %
Rothamsted	123	2·07	7·87	59	2·07	6·24
Woburn	46	2·14	12·72	17	2·39	10·58
Rothamsted, ley–arable	15	1·97	7·5	15	2·13	5·6

domized blocks had a standard error per plot of 11·3 per cent of the mean yield. The figures for randomized blocks from 1939 to 1958, classified according to the method of harvesting, are given in Table 4.

The actual values of the standard errors per plot are nearly the same with the two methods, but the percentage values of the combine-harvested experiments are lower, because the relatively high-yielding crops grown in recent years were almost always harvested by combine. The same effect is shown where all the values are derived from the Rothamsted ley–arable experiment: the binder figures covered the period 1949–53, the combine 1954–57. The experiments at Woburn vary more than those at Rothamsted. The great gain in convenience and scope from using the combine seems to be obtained without any loss of accuracy.

The use of the combine on Broadbalk led to big changes in the handling of the straw. Since the beginning of the experiment the " total straw ", i.e., straw, cavings, chaff and dust had been removed from the field. The threshing results of the last 8 years of binder harvest showed that the chaff and dust taken together amounted to 3–6 cwt./acre according to the yield of straw, and the corresponding figures for cavings were 3–10 cwt. The combine could usually be adjusted to leave a stubble of about the same length as after the binder, but the " total straw " was deposited in a windrow about 4 feet wide in the centre of the track of the machine. The baler followed and picked up this windrow as cleanly as possible and the bales were weighed to give the yield of " straw " as picked up after combining.

In 1958 the amount of debris left on the land after baling was estimated. Six plots were chosen just before harvest where the crop was standing well and the yields appeared to be uniform from end to end. These plots were halved transversely and a single combine cut was taken down the centre of each half. On one half-plot the " total straw " was deposited in a sheet carried behind the machine, on the other half the " total straw " was allowed to fall into windrow and as much as possible was baled. The quantities collected by the two methods, reduced to 85 per cent dry matter, are given in Table 5.

TABLE 5

Broadbalk 1958

Small straw, etc., left on land after baling, cwt./acre

Plot	Years after fallow	On sheet	In bale	Difference
3	1	34·7	23·1	11·6
9	1	51·5	46·8	4·7
10	1	28·9	22·7	6·2
10	4	31·1	23·2	7·9
11	3	28·3	19·5	8·8
18	1	39·1	33·6	5·5
Mean		35·6	28·1	7·5

The amount of debris left behind varied considerably from plot to plot, but with a 10-foot cut the mean figure of 7·5 cwt./acre is actually a dressing of about 19 cwt./acre on the area on which it falls. This is an appreciable addition to the crop residues normally ploughed in on Broadbalk, and a scheme of cutting has been worked out whereby these dressed areas traverse the whole surface of each plot in the course of a 3-year cycle.

Three-course Rotation Experiment: Revised Scheme, Summary, 1952–58

by H. D. Patterson

The original experiment was designed to test the effects of straw, ploughed into the land in autumn or composted, on a three-course rotation of potatoes, barley and sugar beet. Plots receiving straw and NPK fertilizers every second year were compared with plots receiving the same rates of NPK fertilizers but no straw.

The results of the experiment were reviewed at the end of 1951 (*Rep. Rothamst. exp. Sta. for 1951*, p. 135). Dr. E. M. Crowther pointed out that the effects of straw produced in the experiment up to that time might be due to nitrogen immobilized by the straw and potassium provided by the straw rather than to changes in soil structure or organic-matter content.

To test this hypothesis a revised scheme of treatments incorporating separate tests of nitrogen and potassium was introduced in 1952. The compost treatment was discontinued. One-third of the plots previously having straw or compost were now given $53\frac{1}{3}$ cwt. straw/acre ploughed into the land in every second autumn and 0·2 cwt. N/acre (additional to the treatments and basal dressings mentioned below) in the following spring. A further one-third of these plots was given a dressing of muriate of potash, applied in the spring of every second year, calculated to be equivalent to the amount of K_2O supplied by the straw. The remaining one-third of the old straw or compost plots received neither straw nor the potassium equivalent of straw in the new experiment.

Nitrogen and potassium fertilizers were applied at two levels each—0 *v.* 0·4 cwt. N/acre, 0 *v.* 0·5 cwt. K_2O/acre—additional to basal dressings. One-half of all the plots received the lower level of nitrogen in one year and the higher level in the next; in the other plots the phasing was reversed. All plots were split to accommodate the two levels of potassium which alternated between half plots from year to year. Barley and sugar beet were not expected to show large responses to potassium, so half plots were not harvested separately for these crops. There was no test of phosphorus fertilizer.

The nitrogen and straw (or potassium equivalent to straw) treatments were combined as shown in the following scheme for one series of twenty-four plots (treatments shown are additional to basal dressings):

Even years commencing 1952	Odd years commencing 1953	Original treatments: Straw	Compost	Fertilizers
		Number of plots involved		
0·4N	—	2	1	3
—	0·4N	2	1	3
S + 0·6N	—	1	1	—
—	S + 0·6N	1	1	—
S + 0·2N	0·4N	1	—	—
0·4N	S + 0·2N	1	—	—
K_s + 0·4N	—	1	1	—
—	K_s + 0·4N	1	1	—
K_s	0·4N	1	—	—
0·4N	K_s	1	—	—

S: straw.
K_s: potassium equivalent of straw.

The amount of potassium in the straw averaged 0·45 cwt. K_2O/acre, but this varied from year to year from 0·25 to 0·71 cwt. K_2O/acre.

The basal dressings of N and K were the same as in the original experiment, but those for P were increased by 0·2 cwt. P_2O_5/acre.

Basal dressings	Cwt./acre N	P_2O_5	K_2O
Barley	0	0·2	0
Sugar beet	0·2	0·4	0·25
Potatoes	0·4	0·6	0·5

The fertilizers used, both for treatments and basal dressings, were sulphate of ammonia, superphosphate and muriate of potash. All were applied in the spring. For potatoes the fertilizers were broadcast on the flat before planting. This represents a departure from the practice in the original experiment, when fertilizers were placed in the furrows immediately before planting.

TABLE 6

Mean yields of potatoes, 1953–58 (tons/acre)

Treatments to		K_2O (cwt./acre)		Original treatment (1933–51): Straw		Compost		Fertilizers only	
Potatoes	Preceding sugar beet	Potatoes	Preceding sugar beet	Nitrogen (cwt. N/acre) to potatoes 0·4	0·8	0·4	0·8	0·4	0·8
—	—	0·5	0·75	7·54	8·60	7·36	8·52	6·97	8·31
		1·0	0·25	7·80	9·14	7·73	9·07	7·50	8·70
		Mean		7·67	8·87	7·54	8·79	7·24	8·50
		Difference		0·26	0·54	0·37	0·55	0·53	0·39
S + 0·2 cwt. N/acre	—	0·5	0·75	7·96	9·52	—	8·76	—	—
		1·0	0·25	8·44	9·85	—	8·94	—	—
		Mean		8·20	9·68	—	8·85	—	—
		Difference		0·48	0·33	—	0·18	—	—
K_4	—	0·5	0·75	8·05	9·18	—	9·29	—	—
		1·0	0·25	7·96	10·13	—	10·00	—	—
		Mean		8·01	9·66	—	9·64	—	—
		Difference		−0·09	0·95	—	0·71	—	—
—	S + 0·2 cwt. N/acre	0·5	0·75	8·41	9·37	8·44	—	—	—
		1·0	0·25	8·33	9·69	7·86	—	—	—
		Mean		8·37	9·53	8·15	—	—	—
		Difference		−0·08	0·32	−0·58	—	—	—
—	K_4	0·5	0·75	8·02	9·21	8·19	—	—	—
		1·0	0·25	8·55	9·66	8·17	—	—	—
		Mean		8·28	9·43	8·18	—	—	—
		Difference		0·53	0·45	−0·02	—	—	—

Results. Mean yields of potatoes, barley grain and sugar in the revised experiment are set out in Tables 6–8. The results for 1952, the initial year of the revised scheme, are not included, because some plots did not receive their new treatments until 1953.

The mean yields set out in Tables 6–8 tend to support the hypothesis that the total immediate effect of straw ploughed in is to reduce available nitrogen and increase supplies of potassium.

Neither barley nor sugar beet showed any significant response to potassium, but both crops responded to nitrogen, the average responses to 0·4 cwt. N/acre being 3·3 ± 0·27 cwt. barley grain/acre

and 6·4 ± 0·40 cwt. sugar/acre. Apart from a small decrease in the yield of barley at the lower level of nitrogen, straw ploughed in during the autumn with an additional 0·2 cwt. N/acre applied in the spring had little effect on the yields of the following crops of sugar beet or barley. Thus the effect of straw alone, without

TABLE 7

Mean yields of barley, 1953–58 (cwt. grain/acre)

Treatments to		Original treatment (1933–1951)					
		Straw		Compost		Fertilizers only	
		Nitrogen (cwt. N/acre) to barley:					
Barley	Preceding potatoes	0·0	0·4	0·0	0·4	0·0	0·4
—	—	27·2	30·8	29·4	31·7	27·8	31·1
S + 0·2 cwt N/acre	—	26·3	31·2	—	31·2	—	—
K_s	—	27·7	31·9	—	30·6	—	—
—	S + 0·2 cwt. N/acre	28·2	31·0	29·0	—	—	—
—	K_s	27·4	32·0	27·4	—	—	—
	Mean	27·3	31·3	28·6	31·2	27·8	31·1

additional nitrogen, is equal to the effect resulting from a loss of about 0·2 cwt. of applied N/acre, or possibly a little more with barley.

These results are in line with those obtained in the original experiment. Assuming no response to potassium, the responses to nitrogen quoted above and the standard nitrogen response curve,

TABLE 8

Mean yields of sugar beet, 1953–58 (cwt. sugar/acre)

Treatments to		Original treatment (1933–51):					
		Straw		Compost		Fertilizers only	
		Nitrogen (cwt. N/acre) to sugar beet:					
Sugar beet	Preceding barley	0·2	0·6	0·2	0·6	0·2	0·6
—	—	35·9	42·5	34·4	43·0	34·4	41·7
S + 0·2 cwt. N/acre	—	35·7	42·2	—	41·2	—	—
K_s	—	37·6	43·4	—	41·0	—	—
—	S + 0·2 cwt. N/acre	37·0	44·0	34·6	—	—	—
—	K_s	36·9	41·6	37·8	—	—	—
	Mean	36·5	42·7	35·6	41·7	34·4	41·7

the decreases in yield from straw alone would be expected to be about 1·2 cwt. barley grain/acre and about 2·5 cwt. sugar/acre at the higher level of nitrogen. The actual decreases between 1934 and 1951 averaged 1·5 cwt. barley grain/acre and 2·3 cwt. sugar/acre.

Potatoes also responded well to nitrogen. There were also appreciable responses to potassium, but these were somewhat irregular, more so in fact than would be expected from experimental error. As far as can be judged, however, the results do not contradict the hypothesis that potatoes benefit from potassium provided by the straw. Straw together with an additional 0·2 cwt. N/acre applied to potatoes produced almost as good yields as the potassium equivalent of straw. Thus, if the additional nitrogen merely compensated

for losses from immobilization by the straw, as appears to have happened with the other two crops, the benefit from the straw was about the same as that from an equivalent amount of potassium. The increased yield on application of straw to potatoes in the original experiment was 0·42 tons/acre (at the higher levels of nitrogen and potassium), a little but not significantly greater than would be expected from the results of the revised experiment. It should be remembered, in this connection, that the method of applying fertilizer to potatoes and the method of planting potatoes were changed between the two parts of the experiment.

The revised experiment also provides information on the long-term effects of straw applied every 2 years between 1933 and 1951. Both sugar beet and potatoes showed residual effects of the original straw treatments, but there is no evidence of similar effects on barley.

At the lower level of nitrogen the old straw plots yielded, on the average, between 1953 and 1958, 2·1 $\pm$ 0·69 cwt. more sugar/acre than plots receiving fertilizers only throughout the experiment. This difference was considerably decreased by giving 0·4 cwt. N/acre. The old compost plots showed a similar but smaller residual effect.

For potatoes the residual effects were about the same at each level of nitrogen and each level of potassium. The mean yields for plots receiving fertilizers only since 1951 were as follows:

	Original treatment (1933–51):		
	Straw	Compost	Fertilizers only
Mean yield, 1953–58 (tons potatoes/acre)	8·27	8·17	7·87

The difference between the old straw plots and the old fertilizer plots averaged 0·40 $\pm$ 0·144 tons potatoes/acre and is, therefore, significant.

It is of interest to consider whether these long-term residual effects could be caused by residues of nutrients or by some factor or factors influencing the capacity of the crops to respond to nutrients. The average amounts of N, P and K applied per annum (including basal dressings) between 1933 and 1951, allowing for losses in composting and nutrients in straw, were approximately as follows:

Treatment	Cwt./acre		
	N	P_2O_5	K_2O
Straw	0·55	0·45	0·80
Compost	0·45	0·35	0·65
Fertilizers only	0·40	0·40	0·50

Thus the plots originally receiving the largest amounts of nutrients in the first part of the experiment showed the largest residual effects in the second part. Some part of the nitrogen was immobilized by the straw and compost, and may later have become available to the crops.

There are indications that the residual effects may have been related to supplies of nitrogen. The increased yields of sugar on the old straw and compost plots, relative to the old fertilizer plots, were about equivalent to those which would be expected from extra dressings of 0·08 cwt. N/acre and 0·04 cwt. N/acre, respectively.

Also, the residual effects on potatoes in individual years showed a significant positive correlation with responses to nitrogen. However, some factor besides nitrogen is also indicated by the results for potatoes, because the residual effects for this crop were scarcely affected by the addition of 0·4 cwt. N/acre. A proper assessment of the various possibilities on the basis of yield values alone is impossible, but it is at least conceivable that the residual effects on potatoes were associated with both nitrogen and potassium supplies, the response to either nutrient being limited by the availability of the other.

THE FARMS

J. R. Moffatt

Rothamsted

The weather during 1958 was most unusual, and for farming almost disastrous. The year began well after a mild and dry autumn in 1957, and by the beginning of 1958 land work was well ahead; but wet spells, followed by heavy falls of snow early in 1958, delayed seedbed preparations, and what promised to be an early season turned out to be a late one. However, a mainly dry spring helped the sowing, which was completed by early May. All crops made good growth and looked well in the early part of the summer, but a very wet June interrupted all farm work. Much hay was spoilt and some cereals lodged early. The wet, sunless conditions throughout the summer caused severe lodging in cereals, and hopes of a bumper corn harvest were dashed; in fact, the harvest was almost a salvage operation. Root crops grew well, but their lifting was tedious and difficult. The weather remained mild and damp, with the soil very wet throughout the autumn and early winter, so the land ploughed up badly and seedbeds were difficult to obtain. Autumn ploughing and drilling were greatly delayed, little winter corn was sown, and land work has seldom been so much in arrears as it was at the end of 1958.

The Effect of Weather on Crops

All the winter-sown cereals and beans for the 1958 crop started well, as the dry autumn enabled the drilling to be done earlier than usual. Farmyard manure from open yards was carted and spread, and the ploughing soon followed. All the arable fields, except a small area where the beet tops were lying, were ploughed before the end of 1957.

During January and February, mild spells alternated with shorter spells of hard frosts, but a blizzard towards the end of February caused deep drifts of snow.

The ground remained wet, and little land work was possible until mid-March; then for about two months the weather favoured farm work. All spring cereals and beans went in under good conditions, and the tilths for most of the root crops were the best for many years. The germination of all crops was delayed by cold weather, and the winds caused the winter wheat and the grassland to lose their fresh green colour; but in a warmer spell during the latter half of April and early May all crops, including grass, grew rapidly.

By mid-June all crops looked promising, and weeds were under control. Very heavy rain in the latter half of the month affected all farm operations, particularly those to the potato crop. The hay crop was badly damaged, and weeds, particularly in the kale and

potatoes, outstripped the mechanical cultivations. Cereal crops were not much harmed, though there was some lodging of barley and of a few small areas of winter wheat.

The wet, sunless weather persisted until the end of the year, and all operations were much retarded. Most cereal crops became badly lodged, and the start of harvest was delayed until almost the end of August. Much of the corn was combined with a moisture content of about 25 per cent or even above. This greatly strained the drying plant, and much of the corn had to be partially dried and brought back for further drying after harvest. Fair progress was made with the harvesting, but the cereal harvest dragged on until the end of September and the bean harvest until mid-October. Most of the straw was eventually baled, but some had to be ploughed in.

Potato lifting started before the cereal harvest was finished, as this was possible when harvesting was not. When conditions made this work impossible, mangolds were harvested. The lifting of potatoes, mangolds and sugar beet alternated throughout November according to soil conditions, and all work was completed early in December.

Ploughing was done whenever soil conditions permitted, but the land ploughed badly because of the compaction at harvest, and conditions were seldom suitable for working it down. A small area of winter beans was drilled, but very little winter wheat could be sown, and Broadbalk field was not drilled until the second week of December. This month was mostly damp, with widespread and persistent mist or fog.

The ground has remained very wet and intractable throughout the autumn, and field work is much behind schedule. The drilling of winter corn, in particular, is seriously in arrears, and that which has been sown went in under unfavourable conditions.

Field Experiments

The suitable soil and weather conditions in the autumn of 1957 and the spring of 1958 enabled a large programme of field experiments to be sown satisfactorily. At harvest many of the plots were badly laid. However, it was possible to harvest most of them with the combine-harvester, although many had almost been given up as ruined. The wheat on the Six-Course Rotation experiment was too badly lodged even for the combine-harvester, and yields were obtained from small sample strips on each plot. Many of the results will conflict with those obtained under normal conditions, for the general rule this year seemed to be that the better the manuring, the worse the lodging and the lower the yield.

The combining of the classical wheat plots on Broadbalk field in 1957 proved satisfactory, and this has now become the recognized method of harvesting. In 1958, for the first time, the classical barley plots on Hoosfield were cut in the same way. On both fields lodging was severe. The wild oats on these fields were again pulled twice. In Hoosfield, this, together with late sowing following cultivations to encourage the germination and the subsequent destruction of wild oat seedlings, has strikingly decreased the population. However, there was much coltsfoot (*Tussilago farfara*) and

sow thistle (*Sonchus arvensis*). An ester formulation of 2 : 4-D at treble normal strength was applied shortly after harvest and killed the leaves and crowns well. Whether it had any effect on the extensive root system remains to be seen.

The sugar beet and mangolds on Barnfield gave the heaviest yields for many years. The weather was the chief cause of this, but the fact that a good surface tilth was maintained helped rapid and even germination. Singling started under good conditions, which, however, became worse before it was finished. Plants were thinned by hand when it was too wet to hoe.

Trouble caused on the Park Grass plots by moles throwing up many hills was overcome by using poison bait. The first cut, though made late, produced its best hay for some years. The second cut was delayed until late December 1958. Conditions were bad, and some damage was done by the passage of the implements.

Cropping and Rotations

The acreage farmed during 1958 was increased to 460 acres by the addition of 18 acres of old orchard which were cleared and ploughed. Of this total 66 were under permanent grass, 133 under short-term leys and clover or lucerne, and 269 under arable crops. These were 93 acres of wheat, 36 acres of barley, 6 acres of oats, 33 acres of beans, 32 acres of potatoes, 4 of sugar beet, and 15 of kale and mangolds.

A good deal of land low in phosphate or potash is reserved for experiments with these materials, and only a few crops are worth growing under these " famine " conditions. Moreover, many experiments now require sites on which specific crops have, or have not, been grown in the previous year. The provision and choice of suitable sites and the preparation of a cropping schedule have become very difficult. The acreage under cereals has therefore been reduced, and that under beans increased to the maximum that can be conveniently handled. The introduction of a lucerne–grass mixture, sown in alternate rows, was successful; this is another crop that can be used to prevent too frequent cropping by cereals. The acreage of root crops has already reached the maximum that can be dealt with.

Crops

Cereals

All cereal crops looked very well by mid-June, when many were coming into ear. Slight lodging occurred later that month, but the heavy rainstorms during July and August caused the spring oats, and much of the barley and winter wheat, to lodge badly. The spring wheat stood very well. The lodged crops sprouted, and quality generally was poor.

Hormone weedkillers were used extensively, CMPP taking the place of DNOC against weeds such as cleavers (*Galium aparine*) and chickweed (*Stellaria media*). Control was good in the early stages, but fresh growth occurred later, and some crops were very weedy

at harvest. Bindweed (*Convolvulus arvensis*) and chickweed (*Stellaria media*) grew especially vigorously, the former overtopping the cereals in several fields, and the latter spread rapidly over the badly laid crops. This delayed the start of daily operations and resulted in a mass of green material and weed seeds coming in with the corn.

There was much take-all (*Ophiobolus graminis*), especially on crops where wheat or barley had been taken recently.

Cappelle Desprez was the main winter variety grown, but one area of Leda stood and yielded well. Proctor and Herta were the main barley varieties, and Sun II the main oat variety. With all crops the early promise of heavy yields was not fulfilled; but they were better than seemed possible at the start of harvest.

Beans

Only a small acreage of winter beans was sown, but good weather enabled them to be drilled early. There was some frost damage, but the plant recovered and grew well in spring. However, chocolate spot disease (*Botyrtis cinerea*), which is rarely severe at Rothamsted, appeared early and spread rapidly. Severe lodging also occurred, and what promised to be an excellent crop became a poor one.

In the wet season the spring tick beans made too much vegetative growth, but fortunately the black aphis (*Aphis fabae*) attack was slight because the soil and weather conditions at the time when the crops should have been sprayed made this operation impossible.

Under these exceptional conditions the tick beans outyielded the winter strain in the experiment comparing the two. The bean weevil (*Sitona lincata*) was present, but the attack did not require control.

Potatoes

The variety Majestic occupied most of the acreage, with smaller areas under Arran Pilot, King Edward VII and Ulster Supreme. As usual, the whole area was planted with Stock Seed, which went in under quite good conditions. The mechanical cultivations were interrupted by the condition of the ground, and the final earthing up damaged the haulm, despite the use of wheel guards. The lack of cultivations soon showed in the weediness of the fields. Fat hen (*Chenopodium album*) and fumitory (*Fumaria officinalis*) were widespread. Patches of couch grass (*Agropyrum repens*) were sprayed with TCA after lifting, when the stolons were exposed. Late blight (*Phytophthora infestans*) appeared early, but its spread was delayed by repeated applications of copper and dithane fungicides.

Good growth was maintained throughout the season, but the haulm began to turn yellow and die off earlier than usual. After burning off with sulphuric acid the stems of the fat hen (*Chenopodium album*), which would otherwise have impeded lifting, were cut by a machine fitted with horizontally rotating chains.

Lifting was spread over 2½ months because of bad soil conditions, and many of the tubers brought in much soil. Yields were rather lower than usual. The Majestic and Ulster Supreme tubers were almost free from blight damage, but the King Edward were badly affected, and most of this variety was sold off the field. The Ulster

Supremes bruised less readily than in 1957, perhaps because of the longer growing season allowed to the 1958 crop.

Kale and sugar beet

The wet season suited both these crops. An even and regular plant was secured and pests caused little trouble. The mangold fly (*Pegomyia betae*) threatened the beet plants about mid-summer, but a spraying with "Metasystox" controlled this and the slight aphis attack. Constant hand work kept this crop clean, but the kale became very weedy. The sugar beet maintained their growth into the late autumn, and both yield and sugar content were high. Kale also gave a high yield.

Grassland

The early growth of grass was retarded by cold winds until the end of April. When warmer weather came the grass grew rapidly, and for the rest of the year there was an abundance.

The crops for hay were heavy, but cutting was delayed, and some of the crops became rather mature. Much of that cut early was ruined and is only fit for litter, but some of the later-cut crops produced good hay.

In late summer the growth outstripped the needs of the livestock, and the surplus grass was made into silage.

Verticillium wilt attacked both the lucerne–cocksfoot ley, which may have to be ploughed up in 1959, and some of the lucerne plots in the ley–arable experiments.

Livestock

Cattle

As usual, store cattle of about 18 months old were bought in the autumn and winter, and fattened during the following summer and autumn. To this end some 80 Hereford cattle, mainly bullocks, were bought in 1957–58 and outwintered. Some were folded for a time on kale, while others grazed the lucerne–cocksfoot mixture. Hay and a small ration of home-produced concentrate feed was given to all of them. Because grass was scarce full winter rations had to be fed until the end of April. From that time grass was very plentiful—perhaps too lush, as the cattle did not thrive as well as was expected. Very few were fat by the early autumn and feeding of hay, and folding on kale, was started in November. Concentrates were also fed to the more forward beasts to speed their departure to the butcher. The remainder were brought into covered yards about mid-December and fed on silage.

Sixty more bullocks were bought in December 1958 and kept outside, but they are so churning up the wet fields that they will soon be brought into an open yard.

Sheep

The last ewes of the old Scottish Half-bred flock were mated in October 1957 with Suffolk rams to produce lambs to be used on grazing experiments. Thirty-two home-bred gimmers of this cross were also mated to these rams. The lambing was satisfactory, the

old ewes giving a lambing percentage of 174, and the gimmers 131. The gimmers were sold in the spring with lambs at foot. After the lambs had been weaned from the old ewes, the ewes were sold as they became fat. They have been replaced by a new flock of 100 Scotch Half-bred gimmers, which have been mated to Suffolk rams this autumn.

Equipment

Normal replacements accounted for most of the expenditure under this heading, but a concrete-sided silo was erected under the existing barns and filled with new buckrakes.

The platform drier, which was moved in 1957 and re-erected adjoining the circular drying silos of the main grain drying plant, was fitted with its own fan and heaters. A second corn elevator was added to this plant to enable the seed cleaner to be used as a pre-cleaner. This effectively removed the green material and sprouted grain which would otherwise have prolonged the drying operations.

Estate Work

The amount of work involved in the clearing of the derelict orchard in Whittlocks field, bought in 1955, prevented much other estate work. About 75,000 cordon trees and many miles of supporting wire were removed. The land was then ploughed deeply and fallowed for the rest of the year. The field was very foul, and was sprayed in the late autumn with " Dalapon " to kill the couch grass, and also with MCPA.

Staff

J. Hart was appointed Recorder in February 1958.

F. Stokes retired in June 1958 from the position of horseman after almost 30 years of unbroken service.

Woburn

The work of the Woburn Farm is directed and managed by the staff of the Rothamsted Farm. The field experiments are planned by the Field Plots Committee, and the day-to-day planning is done by the bailiff at Woburn.

The unusual weather of 1958 did not affect the crops in the same way as at Rothamsted. The start of land work in the spring was delayed, but all crops grew well in early summer. Most of the barley became lodged shortly before harvest, but the yield of grain was not greatly affected. There was no lodging on either the winter- or the spring-sown wheat, and yields were better than usual. Sugar beet yielded well, and sugar content was high. Beans and potatoes were poor. The King Edward potatoes had a very early and severe attack of Late Blight (*Phytophthora infestans*), which killed the crop before much tuber growth had been made. Autumn land work was held up by the wet weather, and much ploughing remained to be done at the end of the year.

Cropping

Of the 127 acres farmed, 17 were under wheat, 31 under barley, 8 under beans, 26 under potatoes and 6 under sugar beet. There were smaller areas of kale, lucerne and market-garden crops.

Beans were again grown to prevent too-frequent cropping with cereals, and the acreage of potatoes was limited by the presence of potato-root eelworm. The sugar-beet acreage remained constant.

Cereals

Very little winter wheat was sown, but it stood well. Conditions for the sowing of spring corn were not good, and the seeds germinated unevenly, possibly because of uneven depths of sowing. Cage wheels will be used in future on the tractor pulling the drill to prevent the deep wheel tracks usually made on this light land. Most of the areas were treated with herbicides. The exceptionally heavy rain in June and July caused barley and rye to lodge, but the spring wheat stood well. This may indicate that too little nitrogen was given.

Harvest did not begin until about the end of August and was not finished until mid-October. The barley was combined first; yields were better than had been expected, and the quality was surprisingly good for the season. Most of the spring wheat was cut by binder, but on the plots a combine-harvester was used. Yields were heavier than usual. Herta was the main variety of barley, and Koga II the main wheat variety.

Beans

The area under this crop was sown with winter beans, but they were destroyed by birds. A resowing in spring with tick beans produced a good plant, but subsequent growth was uneven. The crop was kept free from aphids (*Aphis fabae*) by spraying with " Metasystox ". The low yield was ascribed partly to inadequate fertilizer treatment, and a rather low but patchy pH status.

Potatoes

These were planted in good time and under good conditions, and grew well during the summer. This and the wet soil conditions made ridging difficult. A very early attack of potato blight (*Phytophthora infestans*), especially on King Edward, the main variety grown, spread rapidly despite three sprayings. Majestic withstood the attack far better, but the haulm began to turn yellow and die off early in August. Both yield and tuber size of the King Edwards were small because the haulm died early, and to sell as much of the crop as possible, lifting started on the worst-affected areas in August, when there was no riddle-size restriction.

Several areas of twitch (*Agropyrum repens*) in the crops were sprayed with TCA when the stolons were exposed after lifting.

Sugar beet

The crop germinated irregularly, and an attack by flea beetle early in May made it necessary to spray with DDT. Good growth

was made during the summer on all except the Six-Course Rotation and the Irrigation experiment, where the plant looked uneven and unhealthy. All areas were sprayed in late June with "Metasystox" to control virus yellows. Because of the mild, wet autumn the crop maintained its growth until it was lifted during November. The sugar content (about 16 per cent) was higher than expected, and remained constant throughout the lifting period. Only the last truck-load, which had been clamped for several weeks, gave a lower figure (14·4 per cent).

Market-garden crops

The season favoured the growth of these crops in the experiment in Lansome field. Heavy yields of red beet and early potatoes were obtained, but the transplanted leeks took some time to get established. Weeds grew thickly throughout the summer, and much hand work was necessary.

Grassland

Grass grew slowly in the spring, and the first cut in the Irrigation experiment was not made until mid-May. Throughout the rest of the season the grassland was very productive, and growth was maintained until the end of the year. A total of eight cuts was made on the Irrigation experiment, the last in mid-November. On the Ley–Arable experiment the grazing plots were stocked almost continuously from early spring.

During a short spell of fine weather in the early part of July the small area of hay was made and baled in good condition.

Field Experiments

Details of these will be found on pp. 185–190 below.

Livestock

Cattle

A bunch of Hereford beasts were bought in December 1957 for fattening, mainly on grass. In the early part of the winter they were fed on hay and sugar-beet tops, the tops being later replaced by a small amount of kale and a cheap concentrated ration. They were all outwintered and fattened well during the summer and early autumn.

A further bunch was bought at the end of the year for fattening in 1959.

Pigs

The sties were further improved. The breeding herd of about twenty Large White sows was maintained. Only 49 per cent of the baconers sold in 1958 were in the AA or AA+ grade, and in an attempt to improve upon this grading a Landrace boar is being used on some of the sows. It is too early to see the effect of this.

Implements

The policy over the past few years has been to replace, gradually, all the out-moded implements by modern equipment, and make Woburn independent of Rothamsted. In the past the conflicting machinery requirements of the two farms have caused much inconvenience to both, particularly at harvest. The usual difficulties were experienced with the 1958 harvest, but these should not recur, as a 10-foot self-propelled combine and a pick-up baler have been transferred permanently to Woburn from Rothamsted. The cereal acreage at Woburn is too small to justify these machines for normal farming, but they are well justified by their advantages when harvesting cereal experiments.

Summary of Cereal Variety Trials at Rothamsted and Woburn, 1955–58

M. J. Hill & J. R. Moffatt

Introduction

Variety trials with winter and spring wheat, spring oats and spring barley incorporating two levels of nitrogen manuring were made on the Rothamsted and Woburn farms between the years 1955 and 1958. Their primary object was to test the suitability of new varieties for use on experiments on the two very different soils, and to compare them with the standard varieties in use on the two farms, but information was also obtained on their response to nitrogen. Trials have not been done with all crops in all years, nor have the varieties grown, or the level of nitrogen used within each trial, been constant.

All the experiments were laid out in a simple randomized block, split plot, design with threefold replication.

Interest centred primarily in yield of grain, but observations were made on all the experiments at Rothamsted, particular attention being paid to lodging.

For the purpose of this summary most of the varieties which were included in only one of a series of trials have been omitted. There are yields for spring wheat and barley at Woburn for only 1 year.

Discussion

Spring wheats. Koga II usually outyielded all the other varieties (Table 1). In the mean yields over the three year period 1955–57 (Table 2) it heads the list at both the high and low levels of nitrogen, although at the high level it is closely rivalled by Svenno. Svenno is interesting because it responds to nitrogen much more than any of the other varieties, and at very high levels of nitrogen it can outyield Koga II, as it did in the 1958 trial. It is, however, somewhat weak in the straw. Atle, which has been replaced by Koga II as our standard variety, has been outyielded by all others, except for Svenno at the low level of nitrogen (Table 2).

In spite of the wet summer of 1958, all the varieties included in this review stood well and there was no sign of lodging at either level

of nitrogen. In 1956, however, some of the varieties lodged badly and their placing, in order of strength of straw, was: (1) Peko; (2) Koga II; (3) Progress; (4) Atson; (5) Atle; (6) Svenno. Peko and Koga stood well, while Atle and Svenno were badly laid on both high and low nitrogen plots. Peko and Progress were on average 5 inches taller than Atle and Atson, and Atson itself was slightly taller than Atle. This indicates that strength is not necessarily associated with shortness of straw. Koga II was the only one successful in combining both these desirable features.

TABLE 1

Spring wheat varieties—mean yields in cwt./acre at Rothamsted and Woburn

Date	N, cwt./acre	Atle	Atson	Koga II	Peko	Progress	Svenno	Mean N response	Previous crop
Rothamsted:									
1955 ...	0·3–0·6	34·7	33·9	40·8	38·1	37·7	36·6 *	−1·1	Potatoes
1956 ...	0·3–0·6	29·7	33·0	33·4	33·9	30·9	30·3	+1·1	Potatoes
1957 ...	0·4–0·8	24·8	26·7	28·8	25·2	25·1	24·5	−0·5	Potatoes
1958 ...	0·4–0·8	24·6	25·0	25·1	25·0	24·8	27·1	+4·1	Spring wheat
Mean ...		28·4	29·6	32·0	30·5	29·6	29·6		
Woburn:									
1958 ...	0·4–0·8	25·8	24·6	27·5	27·7	27·8	24·8	+3·6	Potatoes

* Estimated value. Variety not included in 1955 trial.

TABLE 2

Spring wheat varieties—mean yields in cwt./acre 1956–58 at Rothamsted

Date	N, cwt./acre	Atle	Atson	Koga II	Peko	Progress	Svenno
1956	0·3	26·2	27·8	29·0	27·7	26·5	25·5
1957–58	0·4						
1956	0·6	26·5	28·7	29·2	28·4	27·4	29·1
1957–58	0·8						
Mean response		+0·3	+0·9	+0·2	+0·7	+0·9	+3·6

Barley. Two new varieties, Domen and Ingrid, were tried in 1957 and 1958 alongside the two standard varieties grown on the farm, Herta and Proctor. Plumage Archer was included, as it is grown on Hoosfield and some of the older rotation experiments. Neither at Rothamsted nor at Woburn, with the high or the low levels of nitrogen, were the standard varieties outyielded (Tables 3 and 4). Varieties other than those shown in the tables were included in some years, notably Rika in 1958, and Carlsberg, Maythorpe, Piroline, Provost and Research in 1955. All yielded substantially less than either Herta or Proctor in the one year in which they were tried, and many had other undesirable features.

All plots were scored in 1958, a particularly testing year, for stiffness of straw (Table 8). In 1957 the order was different in so far as both Herta and Ingrid stood better than Proctor, which was more than 50 per cent laid on all high-nitrogen plots. It is disappointing that Domen, which has exceptionally stiff straw, responded so poorly to nitrogen (Table 4).

Table 3

Spring barley varieties—mean yields in cwt./acre at Rothamsted and Woburn

Date	N, cwt./acre	Domen	Herta	Ingrid	Plumage Archer	Proctor	Mean N response	Previous crop
Rothamsted:								
1955 ...	0·23–0·46	40·8 *	47·0	42·1 *	36·7	45·4	−1·8	Potatoes
1957 ...	0·3 –0·6	37·0	40·1	37·8	33·7	40·5	−0·5	Potatoes
1958 ...	0·3 –0·6	28·2	33·5	30·0	27·8	33·6	+5·4	Spring wheat
Mean ...		35·3	40·2	36·6	32·7	39·8		
Woburn:								
1958 ...	0·4 –0·8	31·7	31·9	33·4	28·1	35·6	−0·9	Fallow

* Estimated value. Variety not included in 1955 trial.

Table 4

Spring barley varieties—mean yields in cwt./acre 1957–58 at Rothamsted

N, cwt./acre	Domen	Herta	Ingrid	Plumage Archer	Proctor
0·3	32·1	35·3	32·3	29·7	35·2
0·6	33·2	38·3	35·4	31·7	38·9
Mean response	+1·1	+3·0	+3·1	+2·0	+3·7

Oats. The harvesting of this experiment was always delayed until all the varieties were ripe, which meant some shedding with the earlier ripening ones, and particularly with Pendek.

In 1958 all varieties lodged at the high rate of nitrogen (Table 9); Flamande and Palu stood well at the lower level.

Oats are not important at Rothamsted or Woburn, either experimentally or commercially; Sun II has been the standard variety, and the results summarized in Tables 5 and 6 show that it should now be replaced. Both Sun II and Blenda showed large negative responses to nitrogen.

Table 5

Spring oat varieties—mean yields in cwt./acre at Rothamsted

Date	N, cwt./acre	Blenda	Deva	Flamande	Palu	Pendek	Sun II	de Wattines	Mean N response	Previous crop
1956 ...	0·0 –0·36	23·2	24·9	26·9	27·9	24·2 *	25·3	28·2	+1·6	Barley
1957 ...	0·36–0·72	31·6	31·0	30·0	31·1	30·7	30·9	29·0	+1·4	Wheat
1958 ...	0·36–0·72	32·9	27·5	30·9	35·3	27·9	31·3	33·1	−3·0	Potatoes
Mean		29·2	27·8	29·3	31·4	27·6	29·2	30·1		

* Estimated value. Variety not included in 1956 trial.

Table 6

Spring oat varieties—mean yields in cwt./acre 1956–58 at Rothamsted

N, cwt./acre	Blenda	Deva	Flamande	Palu	Pendek	Sun II	de Wattines
0·36	33·0	29·2	30·6	33·1	31·0	30·8	31·6
0·72	31·5	29·3	30·3	33·3	30·9	27·8	30·7
Mean response	−1·5	+0·1	−0·3	+0·2	−0·1	−3·0	−0·9

Winter wheat. As the nitrogen levels differed greatly in the two trials, mean yields and nitrogen responses are not given, and the results are set out in full in Table 7.

TABLE 7

Winter wheat varieties—mean yields in cwt./acre at Rothamsted

Date	N, cwt./acre	Banco	Cappelle	Heine 7	Hybrid 46	Leda	Minister	Squarehead's Master 13/4	Yeoman	Previous crop
1957	0·4	30·5	40·3	34·3	38·2	42·3	36·7	29·4	22·7	Beans
	0·8	33·7	42·4	40·5	42·4	44·1	38·5	33·8	26·6	
N response		+3·2	+2·1	+6·2	+4·2	+1·8	+1·8	+4·4	+3·9	
1958	0·7	38·8	47·3	44·2	47·0	43·1	46·0	—	—	Beans
	1·2	33·3	48·2	41·7	43·5	34·6	43·3	—	—	
N response		−5·5	+0·9	−2·5	−3·5	−8·5	−2·7	—	—	
Mean 1957–58		34·1	44·5	40·2	42·8	41·0	41·1	—	—	

Yeoman and Squareheads Master 13/4 were grown only in 1957, but the results are included because these varieties are still grown on some of the older experiments. Cappelle, which is the standard variety used at Rothamsted, has consistently outyielded all others except for Leda in 1957. Leda, although excellent for land of low to medium fertility, will not stand high levels of nitrogen, as is shown by the negative response of 8·5 cwt./acre to the higher level in 1958.

Lodging was severe in 1958, and all varieties (with the notable exception of Cappelle) gave a negative response to nitrogen. The plots were scored for strength of straw (Table 10).

TABLE 8

Spring barley varieties—resistance to lodging 1958 *

N, cwt./acre	Domen	Herta	Ingrid	Plumage Archer	Proctor
0·3	9	8	8	7	9
0·6	8	6	5	3	7
Mean	8·5	7	6·5	5	8

TABLE 9

Spring oat varieties—resistance to lodging 1958 *

N, cwt./acre	Blenda	Deva	Flamande	Palu	Pendek	Sun II	de Wattine
0·36	3	4	8	6	3	4	6
0·72	1	1	3	2	1	2	2
Mean	2	2·5	5·5	4	2	3	4

TABLE 10

Winter wheat varieties—resistance to lodging 1958 *

N, cwt./acre	Banco	Cappelle	Heine 7	Hybrid 46	Leda	Minister
0·7	5	8	4	8	6	7
1·2	3	5	2	4	3	5
Mean	4	6·5	3	6	4·5	6

* *Scoring:* 10 Uniform appearance. Every straw erect.
9, 8 } Leaning but not lodged.
5 50% lodged.
1 100% lodged.

Differential nitrogen responses. The experiments were not designed specifically to measure these effects. Varieties and rates of nitrogen application were changed from year to year, the levels of the basal dressings of nitrogen were high, and the sites chosen in the early years were in a good state of fertility. In spite of this, however, three varieties have always given exceptional nitrogen responses. Svenno (Table 2) gave a response of 2·5 cwt./acre greater than the mean, Domen (Table 4) one of 1·5 cwt./acre less than the mean, and Sun II (Table 6) gave a negative response of 2·3 cwt./acre greater than the average of the other varieties.

These experiments suggest that complete freedom from soil-borne cereal diseases is not of the paramount importance that it was thought to be at the start of the series, and that the second white straw crop after a break of 1, or preferably 2, years is a suitable place in a rotation for this type of experiment.

WOBURN EXPERIMENTAL STATION

C. A. Thorold

The programme of field experiments was completed, despite difficult conditions for harvest and the increase in short-term cereal experiments to 366 plots from fewer than two hundred previously.

In common with the rest of England, the June rainfall was excessive, and all months from April to October had less than average sunshine. An important agricultural feature, not shown in the table, was the high humidity in August; the mean value of observations at 9.00 (G.M.T.) was 85·8 per cent relative humidity, in contrast with the 10-year average value of 77·4 per cent relative humidity. There were a few rainless days towards the end of the month, which permitted combine-harvesting of barley on 26–27 August. The percentage moisture in the grain ranged between 16 and 20 per cent. After a short spell of unsettled weather, the combine-harvesting of barley was completed on 1 September. Subsequently, weather was unsettled, and combine-harvesting was not resumed until 9 October, when the spring wheat experiments were cut. The moisture percentage of the grain was then about 30 per cent.

Table 1

Monthly mean temperatures (means of maximum and minimum), total rainfall and daily means of bright sunshine for months of April to October 1958, with departures from long-period means in brackets

Month	Mean temperature, °F.	Rainfall, inches	Bright sunshine (daily mean), hours
April	44·9 (−1·5)	1·06 (−0·44)	4·43 (−0·48)
May... ...	52·7 (+0·7)	2·00 (+0·06)	5·98 (−0·06)
June ...	57·3 (−0·2)	5·32 (+3·36)	4·61 (−2·00)
July ...	60·5 (−0·9)	2·09 (−0·14)	5·82 (−0·22)
August ...	60·4 (−0·3)	2·25 (−0·06)	4·37 (−1·49)
September ...	58·9 (+2·2)	2·73 (+0·42)	4·32 (−0·31)
October ...	50·9 (+1·4)	2·07 (−0·60)	2·95 (−0·44)

Field Experiments

Permanent wheat and barley

These areas were again sown in the autumn of 1957, when both winter wheat (Squareheads Master) and winter barley (Pioneer) were drilled in both areas. Subsequently, spring wheat (Peko) and spring barley (Plumage Archer) were drilled in March 1958. Both autumn and spring sowings germinated so unevenly that it seemed unlikely that useful comparisons between plot yields could be made, and both wheat and barley areas were ploughed in May 1958. An attempt is now being made to resume the experiments in which both wheat and barley are to be grown in both areas. Strips of

winter wheat (Squareheads Master) were drilled across the permanent wheat and continuous barley areas in December 1958, although the land was too wet to provide a satisfactory seedbed. The remainder of these areas will be drilled with barley in the spring of 1959.

Green-manuring experiment

The mean of early potato yields was 10 tons/acre, which exceeds the means in each of the preceding 4 years. Alternate halves of the experiment area have now had early potatoes since 1954, when this experiment was revised.

The fallow plots of the original scheme remain fallow between each main crop in the revised scheme. In 1958 the mean yield of early potatoes on such " continuous fallow " plots was $9\frac{1}{2}$ tons/acre, as compared with a mean yield of $10\frac{3}{4}$ tons when potatoes followed trefoil undersown in the preceding crop of barley. The comparable benefit from undersown ryegrass was smaller, the mean yield of early potatoes being 10 tons/acre. Potatoes after continuous fallow yielded $\frac{1}{4}$ ton/acre less than potatoes after a short fallow after barley; this benefit is attributable to the residues of green manures grown after the previous crop of potatoes.

Attention has been drawn to a general result from this experiment, indicating the importance of the length of time during which organic materials are in the soil before a crop uses them (*Rep. Rothamst. exp. Sta. for 1954*, p. 168). In the revised scheme introduced in 1954 half the plots of each group carrying ryegrass or trefoil after early potatoes are ploughed in autumn and the remainder ploughed in the spring before the barley seedbed is prepared. In 1958 the mean yield of barley, when the preceding green manure crop was ploughed in the spring, was 30·9 cwt./acre, in contrast to 22·8 cwt. when the green manure was ploughed in the autumn.

The 1958 season favoured the green manures grown for testing in 1959. The abundant herbage made it difficult to dry the barley sheaves from some plots undersown with trefoil and ryegrass. In some plots that received only the basal seedbed application of " Nitro-Chalk " (0·23 cwt. N/acre), the undersown trefoil outgrew the barley; this was not accompanied by lodging, which, however, was serious in most of the plots that received additional nitrogen (totalling 0·46 cwt. N/acre).

Six-course rotation experiment

In contrast with the large yield of early potatoes in the Green-manuring experiment, yields of maincrop potatoes were small; for example, in the six-course rotation experiment mean yield was 6·5 tons/acre. The early outbreak of blight (*Phytophthora infestans*) which spread rapidly was responsible. All the experimental potatoes, including the early potatoes, were sprayed with a copper fungicide on 14 July; maincrop potatoes were again sprayed on 29 July and 16 August.

Barley (Herta) and rye (King II) lodged, but the Yeoman wheat stood well, and gave mean grain yields of 20·6 cwt./acre and of straw 28·4 cwt./acre, which have not been exceeded in this experiment since 1948. It is noteworthy that such yields can be attained in the twenty-ninth year of cropping with mineral fertilizers only.

Ley and arable rotations experiment

Future results from this experiment will be somewhat vitiated by the incidence of lucerne-stem eelworm (*Ditylenchus dipsaci*). Two lucerne plots found to be infected in 1957, were ploughed on 29 April 1957 as a safety precaution, instead of lasting into their third year of cropping. J. J. Hesling and D. J. Hooper, Nematology Department, found that the other two third-year lucerne plots were heavily infested in August 1958 and that three of the four second-year lucerne plots (sown April 1957) were affected. The four second-year plots will be ploughed prematurely and remain fallow in 1959, to try to prevent the eelworms developing further. Neither eelworms nor eelworm damage were found in the first-year lucerne (sown April 1958). Fumigated seed was used for the first time in 1958 and will be used for the plots to be sown in 1959. However, plots sown with fumigated seed may still become infested later, and another legume may have to be substituted for lucerne. Sainfoin is, therefore, to be tried on a site adjacent to the experimental area.

Market-garden experiment

Since 1956, early potatoes have replaced cabbages, which previously followed globe beet. The mean yield of early potatoes in 1958 was 7 tons/acre, near to the average of 8 tons in 1956 and 5 tons in 1957. Responses to organic manures are good; in 1958 the mean yields were 8½ tons/acre, with sewage or sewage compost at 20 tons/acre, whereas without organic manure, they were below 5 tons/acre.

The mean yield of saleable bulbs of globe beet in 1958 was 7·9 tons/acre, compared with 8·4 tons/acre in 1957. The percentage of bolted plants in 1958 was 3·78, compared with 0·08 in 1957. However, the extent to which plants bolted depended on the manuring. Without either organic manure or inorganic nitrogen, there was no bolting. The largest percentage of bolted plants (8·4 per cent) came from sewage sludge at 20 tons/acre plus dressings of " Nitro-Chalk ", equivalent to 0·3 cwt. nitrogen/acre. This recently noticed effect is of interest because sewage sludge also produced much bolting in 1950 (*Rep. Rothamst. exp. Sta. for 1950*, p. 129) when the total bolting was more than in 1958.

Irrigation experiment

There were few opportunities for the annual crops in this experiment (spring wheat, spring beans and sugar beet) to benefit from irrigation in 1958. The wheat was watered twice in May, and once in July, each time getting the equivalent of ½ inch of rain. The mean yields of wheat, as cwt. grain/acre, were 24·2 with irrigation and 25·9 without. The spring beans planted 25 March received only two waterings, each of ½ inch in May. Nevertheless, the plants made excessive extension growth over a prolonged period. Many pods shattered and shed beans before combine-harvesting on 15 October.

Some sugar-beet plots received the equivalent of ½ inch of rain

in May. There was no irrigation in June, but two applications in July totalled 1¼ inches. The mean yields of roots per acre were about 14 tons, both with and without irrigation. Sugar percentages also varied only between 16·3 and 16·5 per cent, and the general mean was 45·4 cwt. sugar/acre.

The first application of water to plots in the area of permanent Cocksfoot grass was on 2 May, when the equivalent of ¾ inch of rain was given. Table 2 shows the weights of grass at each cutting and the amounts of nitrogen removed, calculated from nitrogen determinations made on samples taken at each cutting.

TABLE 2

Weights of dry grass (G) and of nitrogen (N) removed (cwt./acre) at each cutting, with and without irrigation, and at different rates of nitrogen application, in 1958

Date of cut	Without irrigation				With irrigation			
	0·3 cwt.		0·6 cwt.		0·3 cwt.		0·6 cwt.	
	G	N	G	N	G	N	G	N
14 May ...	7·7	0·3	8·4	0·4	9·3	0·3	10·9	0·4
3 June ...	7·9	0·3	10·5	0·5	8·7	0·4	11·1	0·5
24 June ...	13·4	0·4	20·3	0·8	13·4	0·4	14·6	0·6
15 July ...	10·8	0·3	11·5	0·4	10·2	0·3	10·5	0·4
6 Aug. ...	8·6	0·3	8·6	0·4	10·9	0·4	12·6	0·5
5 Sept. ...	15·6	0·5	20·5	0·8	15·7	0·5	18·8	0·7
8 Oct. ...	6·1	0·3	5·2	0·2	5·5	0·2	4·4	0·2
14 Nov. ...	3·0	0·1	2·6	0·1	2·4	0·1	2·1	0·1
Total ...	73·1	2·5	87·6	3·6	76·1	2·6	85·0	3·4

There were eight nitrogen applications, at 0·3- and at 0·6-cwt. levels, respectively, totalling 2·4 and 4·8 cwt. nitrogen/acre.

Irrigation amounted to 2·0 inches in May, 0·5 inches in June, 1·25 inches in July and 0·5 inches in August (total 4·25 inches).

Although the total yield for all cuts with irrigation differs from that without irrigation by less than 1 cwt./acre when the two nitrogen levels are combined, there were indications of benefit from irrigation in the first two cuts (14 May and 3 June). Subsequently, yields at each cut with and without irrigation were similar.

Amounts of nitrogen removed in the grass reflect the levels of "Nitro-Chalk" applied, but total amounts were unaffected by irrigation.

Short-period experiments with wheat and barley

Combine-drilling of nitrogen. Two experiments, with Herta barley and Peko wheat respectively, were done to observe the effects of combine-drilling the seed with different compound fertilizers, containing nitrogen at three different levels (0·22, 0·54 and 0·72 cwt. N/acre) in comparison with similar dressings of nitrogen applied as sulphate of ammonia, broadcast on the seedbed after drilling. All plots received the same amount of potash and phosphate, combine-drilled.

The barley lodged at the two higher levels of nitrogen, both when combine-drilled and when broadcast. There was little lodging at the lowest level of nitrogen and with no nitrogen. In contrast to

the barley, the wheat stood well at all three levels of nitrogen,when combine-drilled and when broadcast.

Glume blotch (*Septoria nodorum*) attacked the wheat in this experiment, and incidence was more severe in plots which received most nitrogen.

With barley, combine-drilling at all rates was equal to, or better than, broadcasting, but with spring wheat combine-drilling depressed yield. A similar depression occurred with barley at Woburn in 1957, and because of these inconsistencies, the experiments will be repeated in 1959.

Time and quantity of nitrogen. Two experiments, with Herta barley and Peko wheat respectively, were designed to compare three levels of nitrogen (0·3, 0·6 and 0·9 cwt. N/acre, as " Nitro-Chalk "), given as one application (in seedbed; as an early top-dressing; as a late top-dressing or as two applications (seedbed and early; seedbed and late; early and late top-dressings), or as three applications (seedbed, early and late top-dressings).

Barley lodged even at the lowest level of nitrogen, and at the highest level all plots were badly laid. The amount of lodging was more related to total quantity of nitrogen applied than to time of application. The wheat stood well even at the highest level of " Nitro-Chalk " application (0·9 cwt. N/acre). With spring wheat, the single seedbed dressing was at least as good as other methods of application. With barley, early top-dressing seemed somewhat more effective than seedbed application. (See above, p. 164.)

Comparisons of spring wheat and barley varieties at two levels of nitrogen. The following varieties were compared at 0·4, and at 0·8 cwt. N/acre:

> *Wheat:* Atle, Atson, Koga II, Miana, Peko, Progress, Svenno.
> *Barley:* Domen, Herta, Ingrid, Plumage Archer, Procter, Rika.
> (See above, pp. 181–182.)

Jerusalem artichoke

Trials have continued at Woburn since 1954 on the so-called " Topine " strain of Jerusalem artichoke, which is reputed to be especially luxuriant. Both tops and roots might be profitably used as fodder for stock. Topine, like artichoke, is normally planted in April. As the tops are liable to be damaged by frost, it seems desirable to cut them in October, or possibly earlier, when required for fodder, but it is not known whether the yield of roots is adversely

TABLE 3

Weight of Topine and of Jerusalem artichoke tops, cut in October 1958

	Fresh weight, tons/acre	Percentage dry matter	Dry weight, tons/acre
Topine	20·2	22·1	4·8
Artichoke	10·6	21·1	2·2

affected by removing the tops while green. An area of about 0·1 acre was therefore planted with Topine and ordinary artichoke in alternating rows on 28 April 1958. The rows were 2 feet apart, and the plants were spaced at 1·3 feet apart in the rows. The tops in

one-half of the area were cut by hand and weighed on 30 October 1958. The other tops will not be cut until all roots in the whole area are lifted and weighed about February 1959.

Table 3 shows that the Topine tops weighed twice as much as tops from ordinary artichoke, but yields of roots will not be known till 1959. (Mann and Barnes.)

DUNHOLME FIELD STATION

R. Hull

W. J. Byford was appointed in March to the vacant post of plant pathologist.

R. A. Dunning attended the meeting of the Virus Committee of the International Institute of Sugar Beet Research in Holland in January. S. N. Adams attended the Summer Congress in Belgium in June, and visited research centres in Belgium and Holland.

Sugar-beet yellows

More information has been collected on which to base advice about the time to spray sugar-beet crops with systemic insecticide to control yellows. The winter hosts of sugar-beet aphids were examined during March and April, and during May, June and July the agricultural staff of the British Sugar Corporation counted aphids in about 2,000 fields each week. A summary of this information was distributed each week to National Agricultural Advisory Service and the British Sugar Corporation staff. Spraying was recommended when local infestations of green aphids were detected or the population reached an average of 0·2–0·3 green aphids/plant in any area. Warnings to spray were posted to growers by the factory staffs, and most growers in the Eastern Counties had received a warning by late June. About 100,000 acres were sprayed, although spraying was curtailed by wet weather in some areas. At the end of September the incidence of yellows was two to three times more in unsprayed fields than in sprayed ones in the same localities.

Few *Myzus persicae* were found in spring on brassica crops or weeds; the heaviest infestation encountered was on *Lepidium campestre* near Bury St. Edmunds. *M. persicae* were common on clamped mangolds, and on occasional sugar-beet plants in sheltered places. Aphids from beet and mangold were the only ones which, when transferred to glasshouse plants, caused severe (necrotic) yellows. *Myzus ascalonicus* was the most common aphid on weeds, especially *Stellaria media*. Some beet to which they were transferred in the glasshouse developed mild yellows. (Dunning and Hull.)

At the end of April aphids were found in thirteen of twenty-eight mangold clamps examined, and the number of times the various species were recorded were: *Myzus ascalonicus* 3, *M. persicae* 8, *Rhopalosiphoninus staphyleae* 11, *Aulacorthum solani* 3. These species and *Macrosiphum euphorbiae* were found on sugar beet in the field during May and June. In the glasshouse their relative ability to colonize sugar beet was, in descending order, *Aphis fabae* and *M. ascalonicus*, *A. solani* and *M. persicae*, *M. euphorbiae* and *R. staphyleae*. (Dunning.)

A few *M. persicae* were found on wild beet growing on the Shotley peninsula in Suffolk in December 1957, but not later though at least 200 shoots were examined weekly during April, May and

June, and less frequently in July, August and September. Sticky-traps caught flying aphids above the sugar-beet crop from the first week in May, whereas no aphids were trapped above wild beet until 2 weeks later. *M. persicae* was first found on nearby sugar-beet crops in the first week of June, and a fortnight later the aphid population was, on average, 0·5 aphids/plant.

Healthy sugar beet in pots were placed among wild beet, and left exposed there for two weeks, when they were returned to the glass-house and replaced by fresh plants. Over the 10-week period starting in the second week of April, only one of the 600 plants exposed developed yellows and three developed mosaic.

Yellows appeared in sugar-beet crops near the wild beet during the second week of June, but no plants showed mosaic until late June. 60–80 per cent of the nearby wild beet showed mosaic and 30–50 per cent yellows.

In two sugar-beet crops adjacent to sea-walls colonized by wild beet, the proportion of plants with yellows increased with distance from the sea-wall. In the spring and summer of 1958 there was no detectable spread of yellows from wild beet on the Shotley peninsula to nearby sugar beet. (Gibbs.)

Yellows was prevalent in seed crops, as was expected from examining steckling beds in the autumn of 1957. On average, 10 per cent of sugar-beet seed plants and 31 per cent of mangold seed plants had yellows in June, the highest incidence since the steckling certification scheme started in 1951. Crops planted with stecklings raised in isolated areas, or under a cover crop, had respectively, 1·4 and 3·4 per cent of plants with yellows; those from open beds depending for yellows control on spraying with systemic insecticide had 23·6 per cent. Only spraying has yet been used for mangold stecklings, which accounts for the greater incidence of yellows. Aphids did not colonize seed crops in the spring and obvious spread from seed crops to root crops was rare.

The 1958 stecklings were comparatively free from yellows; in October all sugar beet and 95 per cent of mangold steckling beds had less than 1 per cent affected plants. (Dunham and Hull.)

Varieties selected at Dunholme for tolerance to yellows were tested in the field at Harkstead, near Ipswich, where yellows became prevalent during August. Some of the selected varieties had fewer plants with yellows at first, and looked greener than the commercial varieties throughout the season. Variety 57/6/5 yielded 21 per cent and Variety 57/21/2 yielded 15 per cent more sugar per acre than the best of four commercial varieties.

At Dunholme the number of *M. persicae* infesting plants of sixty varieties in July varied greatly and was directly related to the proportion with yellows. The slower spread of the disease in tolerant varieties may be partly due to their relative unsuitability for *M. persicae*; also they show symptoms more slowly when infected with yellows.

Most of the varieties used at Harkstead were also tested at Kirton, near Boston, where downy mildew (*Peronospora schachtii*) was prevalent. The experimental varieties were more susceptible to this disease than commercial varieties, and in early July half of the plants on some plots were infected. This reduced yield, and variety 57/21/2,

for instance, here gave only 68 per cent of the sugar yield of the commercial varieties instead of outyielding them as at Harkstead. No experimental variety outyielded the commercial varieties at Kirton.

Production of seed and testing of other selections was continued at Dunholme. Both downy mildew and powdery mildew (*Erysiphe* sp.) were prevalent and varied strikingly between the varieties. (Hull.)

When *M. persicae* were offered the choice in the glasshouse of healthy or diseased sugar-beet leaves, they preferred those with severe yellows to mild yellows and these to healthy. They preferred young to mature leaves of healthy plants, but from infected plants they preferred whichever leaves showed most severe symptoms. They multiplied quicker and lived longer on infected than on healthy sugar beet, so three factors contribute to making infestations on infected plants greater than on healthy. *M. ascalonicus*, *Aphis fabae* and *Aulacorthum solani* behaved similarly.

Differences in preference of *M. persicae* for healthy plants of various inbred lines of sugar beet disappeared or were reversed when the lines were infected with yellows. Increases in preference and reproduction rate caused by spraying leaves of healthy plants with sucrose, casein hydrolysate or caffeine, or detaching the leaves from the plant, were small compared with those caused by infection with yellows. (Baker.)

Twelve field experiments done in conjunction with the British Sugar Corporation determined the effect of two times of spraying with " Metasystox " on yellows incidence and on yield, and checked the timing of the spray warnings issued to farmers. Yield responses depended on the incidence of yellows on the unsprayed plots and ranged from nil at some sites to an increase of 5·7 tons/acre of roots and 1 per cent in sugar content on the twice-sprayed plots at the Norfolk Agricultural Station. Sprays in early or late June mostly gave similar effects; this contrasts with results in 1957, when only early sprays were effective, but parallels results in most previous years. A second spray had only a small additional effect where an earlier one had been given, although it often paid.

Sugar beet grew luxuriantly in the mild, moist autumn. Samples taken from the spraying experiment at Sprowston showed a yield increase between 25 September and 6 November on unsprayed and sprayed plots respectively, of 1·8 and 2·9 tons/acre of roots and 7·8 and 12·9 cwt./acre of sugar. Spraying to control yellows augmented this autumn growth, and commercially spraying 100,000 acres doubtless contributed to achieving a record yield of sugar beet forecast in 1958. (Dunham, Dunning and Hull.)

Insecticides

Several insecticides were tested at Swaffham, Norfolk, to control yellows' vectors. All were applied on 20 June in 60 gallons/acre of water; the amount of active insecticide per acre and the percentage of plants with yellows in September were: 15 oz. DDT, 22 per cent; 6 oz. " Ekatin M " 30 per cent; 8 oz. " Megatox " (fluoroacetamide) 16 per cent; 6 oz. " Metasystox " 13 per cent; 2 oz. " Phosdrin " 16 per cent; 5·1 oz. " Rogor " 18 per cent; unsprayed 32 per cent. Yellows incidence was roughly inversely proportional to the degree

of aphid control achieved in June and July. In the autumn at Dunholme stecklings sprayed with fluoroacetamide and " Ekatin M " were colonized by *A. fabae* more rapidly than those sprayed with " Metasystox " and " Rogor ". The effect of these sprayings at 2-, 3- or 4-week intervals on yellows incidence will be assessed on the transplanted seed crop next spring.

" Phosdrin " at 4 oz./acre, " Metasystox " at 6 oz./acre and fluoroacetamide at 6 oz./acre each gave good control of aphids when sprayed in 50 gallons/acre of water on to mangolds in the field on 12 November 1957. " Phosdrin " killed the aphids fastest, and fluoroacetamide slowest. DDT (15 oz./acre) and γ-BHC (1·8 oz./acre) reduced the number of aphids 3 days after spraying, but 12 days later they were as numerous as on the unsprayed plots.

The amount of fluoroacetamide fell from a maximum of 8 p.p.m. in the mangold leaves shortly after spraying to $<0{\cdot}1$ p.p.m. in any part of the mangold in April 1958; the equivalent figures for γ-BHC were 1·2 and 0·1–0·4 p.p.m.

The systemic insecticides " Disyston ", " Thimet " and " Rogor " were tested as seed dressings on rubbed and on natural sugar-beet seed, at various rates averaging respectively 0·625, 2·5 and 0·78 per cent active ingredient. The rubbed seed was sown at 8 lb./acre and the natural at 16 lb./acre. All dressings, and especially " Disyston ", caused cotyledon-tip scorch, but even the highest rates had negligible effect on final plant stand. Granular " Thimet " (0·25–1 lb./acre) and " Disyston " (0·5–2 lb./acre) drilled along with the seed gave a similar phytotoxic effect, but not when broadcast. The higher rates of seed dressing with " Thimet " and " Disyston ", and all soil treatments, gave complete control of *Pegomyia betae* larvae mining in the leaves up to 7 weeks after sowing. The broadcast soil treatments halved the incidence of yellows in September.

Seed treated with " Disyston " (2·5 per cent w/w active ingredient) or with " Thimet " (0·625 per cent) was sown at sixty-one sites distributed throughout beet-growing areas; rubbed seed was sown at 8 lb./acre or natural seed at 16 lb./acre. On average " Thimet " had no effect on emergence or growth, but " Disyston " reduced both slightly. Both treatments reduced attacks of mangold fly, flea beetle, black and green aphids. Seed treatment with systemic insecticides gave the best initial kill of aphids on stecklings during August and early September, but granular " Disyston " applied to the seedbed at 1½ lb./acre of active ingredient had a more persistent effect. A combination of seed and soil treatment produced the lowest incidence of yellows in early November, 1·5 and 1·7 per cent for " Thimet " and "Disyston " respectively, as compared with 5·6 per cent on the untreated plots.

The incidence of yellows in a seed crop was reduced from 47 to 32 per cent by sowing, in the autumn of 1957, seed treated with " Thimet "; " Disyston " was slightly less effective. Spraying the stecklings with " Metasystox " lowered yellows incidence still further. (Dunning.)

Seed treatment

A three-year series of seed-dressing trials, arranged in conjunction with the British Sugar Corporation field staff on seventeen to nine-

teen widely scattered sites each year, was ended. The seed treatments tested were steeping seed for 20 minutes in 40 p.p.m. ethyl mercury phosphate solution, dusting with γ-BHC, dieldrin or aldrin at 0·67 per cent w/w, and also commercial combined organo-mercury/insecticide dusts. The treatments affected the rate of delivery of seed from the seed-drills, so seedling counts have been adjusted for seeding rate, but counts of final plant stand after singling have not.

EMP-steeped seed gave, on average, 39 per cent more seedlings than untreated seed, and 7 per cent more plants in the final stand. The corresponding increase over organo-mercury dust treatments were 11 and $2\frac{1}{2}$ per cent respectively. EMP plus dieldrin gave the same increase in seedlings over untreated seed as did EMP alone; EMP plus γ-BHC and EMP plus aldrin depressed the number of seedlings by 3 and 6 per cent respectively compared with EMP alone. Neither aldrin nor γ-BHC affected the final plant stand, but dieldrin gave a 3 per cent increase. The commercial organo-mercury dry dressings containing dieldrin gave a slightly greater final stand of plants than one containing γ-BHC, which was itself slightly greater than one containing aldrin. (Dunning and Gates.)

Satisfactory emergence of seedlings was obtained in the field from seed steeped in 10 p.p.m. EMP solution. Emergence fell off with concentrations between 80 and 160 p.p.m. and, with concentrations greater than 240 p.p.m., emergence was less than with the untreated control. EMP sprayed on to seed gave no consistent effect up to 8 per cent v/w of an EMP concentration of 0·3 per cent, or 2 per cent v/w at a concentration of 0·8 per cent EMP. Methoxy ethyl mercury acetate (MEMA) applied as a spray at 2 per cent v/w was almost as good as when applied as a 60-p.p.m. steep, but neither treatment was as effective as 40-p.p.m. EMP steep.

The quantity of fungicide on individual seeds and regularity of distribution obtained by spraying was assessed by a *Stemphylium*-agar-plate method. A distribution of fungicide most nearly approaching that given by soaking was obtained by applying slowly 6 per cent v/w of 0·2 per cent EMP solution.

Batches of seed giving poor germination in laboratory tests responded more to EMP steep than seed of good germination, and when seed of a batch heavily infected with *Phoma betae* was graded for size small seed responded more to EMP steep than large.

Treating EMP-soaked seed with " Phygon " or TMTD depressed seedling emergence. The antibiotic seed treatment " Rimocidin " depressed emergence when used as a steep at 200, 400 or 800 p.p.m. for 16, 8 or 4 hours respectively. Seed treated with a dust containing griseofulvin and an organo-mercury compound gave seedling emergence comparable to that obtained with EMP steep. (Byford.)

" Docking disorder " was unusually prevalent in 1958, not only at Docking itself, but also at other places in Norfolk, Suffolk, Lincolnshire, Shropshire and Yorkshire. At each place sugar beet grew poorly on patches of sandy soils of high pH. The leaves often showed signs of nitrogen or magnesium deficiency, were thickened, cupped and had xeromorphic characteristics. The tap roots were stunted and laterals, or tap root, sometimes grew horizontally only a few inches under the soil surface. Especially after rain many fresh

adventitious rootlets grew; later their tips stopped growing, swelled and the rootlets died. This sequence was often repeated, so main roots acquired a beard of dead and dying rootlets.

The soil in the affected patches was structureless and slaked completely when moistened; it showed the following differences from that in which normal beet grew near by: (1) a higher coarse-sand fraction; (2) a lower clay content; (3) a lower organic matter content; (4) a lower base-exchange capacity; (5) a lower active carbonate content.

The roots of affected beet contained no more fungi, bacteria or nematodes, nor a different range of species of these organisms, than did roots of unaffected beet. No virus could be isolated by sap inoculation from affected roots on to *Chenopodium amaranticolor*. Affected beet from the field, replanted into pots of John Innes compost and kept in the glasshouse, recovered completely and produced normal leaves and roots.

Beet raised from seed in pots of affected soil grew poorly and had dead rootlets. In affected soil mixed with an equal weight of John Innes compost they grew as well as in compost alone or in unaffected soil from the field. Heating the affected soil in an autoclave for $\frac{1}{2}$ hour only very slightly increased growth.

These results suggest that the trouble is not caused by a pathogen (see *Rep. Rothamst. exp. Sta. for 1954*, p. 95; 1955, p. 106; 1956, pp. 119–120) but by the unusual soil type. (Gibbs.)

Other diseases

Two sprays in April with " Agrimycin 100 " (streptomycin) " Agrimycin 500 " (streptomycin and copper) or with Bordeaux Mixture did not effect the incidence of downy mildew in four Lincolnshire sugar-beet seed crops, where it varied from 3 to 11 per cent.

Pleospora betae, previously recorded only on *Beta vulgaris*, was found in April on dried stems of *Beta trigyna* at Dunholme. (Cornford.)

Sugar-beet Manuring

The main work is a series of field trials conducted in co-operation with the field staffs of the British Sugar Corporation. The harvesting of these trials is not completed until December and the analyses for sugar content until early in the New Year. This report gives the results of the 1957 experiments and indicate the trends from the few 1958 results yet available.

NPK–dung trials

Sixteen 3^3 factorial experiments tested 0·6, 1·2 and 1·8 cwt. N/acre as sulphate of ammonia; 0, 0·5 and 1·0 cwt. P_2O_5/acre as superphosphate and 0·8, 1·6 and 2·4 cwt. K_2O/acre as muriate of potash. In thirteen of these trials the mineral fertilizers were tested in the presence and in the absence of dung.

Without dung, the best dressings were 0·6 cwt./acre N, 0·5 cwt./acre P_2O_5 and 0·8 cwt./acre K_2O; and higher rates depressed sugar yield. In the presence of dung, 0·6 cwt./acre N was still the best dressing, but the dung provided all the P and K needed. High

rates of nitrogen in the presence of dung depressed sugar yield considerably.

Dung gave an extra 2·2 cwt. sugar when only 0·6 cwt./acre N was applied, but this advantage was largely eliminated by more nitrogen.

These optimum dressings are lower than is usually thought desirable for sugar beet. Most seasonal factors in 1957, however, operated against high fertilizer responses. The 1956–57 winter was drier than average, the spring of 1957 was exceptionally dry, and there was a particularly early and severe attack of virus yellows.

Ploughing down of P *and* K *trials*

Nine experiments compared seedbed application of 1·0 cwt. P_2O_4/acre as superphosphate and 1·5 cwt. K_2O/acre as muriate of potash with the same fertilizers applied in the previous autumn and ploughed in. Responses to phosphate were very small, whether it was broadcast or ploughed down. Broadcast potash increased yield by 2·8 cwt./acre sugar, compared with 1·7 cwt. for potash ploughed down. At seven out of nine centres broadcasting was better than ploughing down.

Comparison of forms of nitrogen fertilizers

Nine experiments compared the effect of 0·6 cwt./acre N applied as sulphate of ammonia, calcium nitrate or urea in the seedbed or as a top-dressing at the time of the last hoeing. Treatments of an additional 0·6 cwt./acre N applied either in the seedbed or as a top-dressing were also included.

Top-dressing raised the sugar yield less than the same quantity put on the seedbed, and there was no advantage in splitting the heavier dressing. Calcium nitrate and urea differed little from sulphate of ammonia in their efficiency for sugar production.

Trends in the 1958 experiments

Early results from the 1958 NPK–dung experiments suggest that responses to nitrogen have been higher this year. 1·2 cwt. N/acre has given a higher sugar yield than 0·6 cwt. N at six out of eleven sites where dung was not applied. 1·8 cwt. N/acre, however, gave less sugar than 1·2 cwt. N at all eleven sites. In the presence of dung, the highest sugar yield was always given by 0·6 cwt. N.

0·5 cwt. P_2O_5/acre seems to be the optimum level of phosphate, both with and without dung, and there has been no advantage in exceeding 0·8 cwt. K_2O/acre. These results are similar to 1957, except that in that year dung provided all the phosphate needed by the crop.

The ploughing-down trials are showing the same trends as last year; in five out of six trials broadcast P and K gave more sugar than ploughing down.

Early results of the types of nitrogen experiments indicate that there was no advantage in splitting the nitrogen dressing even in this abnormally wet spring.

The effect of salt and potash on sugar beet on the Lincolnshire Limestone soils

A series of 2^2 factorial experiments on the Jurassic Limestone soils of Lincoln Edge is testing the effect on sugar beet of 1·5 cwt. K_2O/acre as muriate of potash and its chemical equivalent of salt ($1\frac{3}{4}$ cwt./acre). All plots received 1·0 cwt. N/acre as sulphate of ammonia and 0·5 cwt. P_2O_5/acre as superphosphate. There were six experiments in 1957 and five in 1958. The results expressed in yield of sugar/acre are shown in Table 1.

Table 1

Effect of salt and potash on sugar yield (cwt./acre)

	1957, mean of 6 trials	1958, mean of 5 trials
N, P only	36·4	42·1
N, P + salt	40·8	47·8
N, P + potash	40·1	45·7
N, P + salt + potash	40·6	49·7

In 1957 salt and potash were equally effective in raising sugar yield. When salt was applied, there was nothing to be gained from using potash, and *vice versa*.

In 1958 salt gave an average yield response of 5·7 cwt. sugar, compared with a response of 3·6 cwt. sugar to potash. Even when potash was applied, salt gave a response of 4·0 cwt. sugar. Potash in the presence of salt gave a yield increase of 1·9 cwt./acre, which is just profitable.

Chemical work is in progress to see if the response at individual sites can be related to soil K and Na.

Growth analysis of sugar beet receiving different levels of nitrogen fertilizer

High rates of nitrogen cause sugar beet to produce more top, but the plant is normally unable to use this extra leaf to increase its sugar yield. To obtain more information on this effect of excessive nitrogen, a growth analysis was conducted on beet at Dunholme receiving 0, 0·6, 1·2 and 1·8 cwt. N/acre. Sub-plots were harvested nine times throughout the growing season, and both fresh and dry weights of leaves, petioles and roots and total leaf areas were determined.

A dressing of 1·8 cwt. N/acre is normally excessive for sugar production, but the site chosen was exceptional in that yield responses were obtained up to the highest level of N. No dressings were therefore excessive, and the main object of the trial was not achieved. It was of interest that leaf area and dry-matter accumulation on plots receiving 1·8 cwt. N/acre were depressed in the early months. Not until August did the leaf area of the 1·8 cwt. N treatment exceed that of the 1·2 cwt. N, and the superiority in dry-matter production did not appear until September.

Effect of sowing and lifting date on response to fertilizer

An experiment was carried out at the Lindsey Farm Institute in 1958 to see if the dates of sowing and lifting affect the response of

sugar beet to fertilizer. All plots received a basal dressing of 5 cwt. kainit/acre, and half received in addition 8 cwt. "Fison's 32" (12 : 9 : 9)/acre. There were three sowing dates: 15 April, 29 April and 13 May; and three lifting dates: 2 October, 30 October and 3 December.

Late sowing depressed sugar yield, but did not affect response to fertilizer. Results from the three lifting dates show a remarkable increase in sugar production in October, but delayed lifting did not affect response to fertilizer. (Adams.)

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

J. P. Watson resigned and P. Bullock, W. M. Corbett and C. W. Montgomery were appointed. J. C. Chisnall of the Colonial Pool of Soil Surveyors died in Sierra Leone; other members are continuing surveys in the countries to which they were seconded and A. R. Stobbs was appointed. R. R. Storrier and J. Loveday returned to Australia after obtaining higher degrees. B. Clayden, C. C. Rudeforth and R. S. Seale returned from Iraq and have taken part in the season's work. A. Muir attended a meeting of a Working Party on Soil Classification, etc., in Baghdad and afterwards visited Teheran at the invitation of the Foreign Office. D. A. Osmond attended a symposium on soil structure at Ghent. H. H. Le Riche obtained a Ph.D. degree at London University.

Field work was completed on Sheet 83 (Formby) and is being continued on sheets as described below. The soil map of Great Britain and N. Ireland at 1 : 1,000,000 was prepared for incorporation into the Food and Agriculture Organization map of the soils of Europe; it will also be used by the Clarendon Press in a forthcoming atlas. Several maps are in course of production in the cartographic section, and a very interesting exhibit of the stages from field-slip to the published map was set up at the Autumn meeting of the British Society of Soil Science at Bangor.

Northumberland

Sheet 19 (Hexham)

Mapping on the 1 : 25,000 scale has progressed westwards, north and south of the Tyne and in Allendale. The most interesting area is that including Corbridge and Hexham, which is approximately bisected by the Tyne flowing in an east-south-easterly direction. Excluding the higher land above 700 feet, where gley soils, podzols and other moorland types predominate, the Tyne is a significant pedological boundary for, on the north bank, where the slopes are generally south-facing, the ratio of brown earths to gley soils is about 3 : 1. South of the river poorly drained soils are dominant, brown earths are relatively rare and the ratio is about 1 : 7. The fairly large spread of alluvium in the valley is mainly well drained and, although variable in texture, is mostly covered by sandy and light loams.

Allendale consists mainly of high moorland with soils similar to those described in previous years. The valley sides have been extensively worked for various minerals, so that spoil heaps and disturbed soils are extensive. Brown earths and associated soils occur on the lower slopes where most of the agricultural holdings are situated; the fell is traditionally rough grazing, for, as a common,

its stocking is limited by ancient bye-laws. Consequently, except for heather-burning, little or no improvement has been attempted. (Ashley and Rudeforth.)

Yorkshire

Sheet 71 (Selby)

Nearly all the land west of the Derwent was mapped as well as about half of that beyond it. The soils encountered were those associated with the Escrick Moraine, which have been described before.

When the growth of crops prevented mapping on Sheet 71, work was started around Settle and planned so as to provide the groundwork either for detailed mapping of Sheet 60 (Settle) or for a reconnaissance of the larger Sheet 90 (Seventh edition). The area straddles the Craven Fault with the Mountain Limestone to the north and the drumlin country, mainly of heavy Carboniferous Boulder Clay, to the south.

A reconnaissance was made of Farndale, which may be regarded as typical of the dales of the N. Yorkshire Moors. The lower slopes of the valley are gentle and have heavy, poorly drained soils on Liassic clays which resemble those on Carboniferous shales. The steeper and more broken slopes above have better drained soils on sandy shales which give way, higher up, to podzols on sandstones. The valley slopes end abruptly, often in a cliff which separates them from the flatter moorland where peaty gleys and soils with thin iron pan are dominant. (Crompton.)

Lancashire

Sheet 83 (Formby)

Detailed mapping has been completed, and soil boundaries are being checked and profiles sampled on Sheets 83 and 74 (Southport), both of which will be described in one memoir. Most of the soils encountered have already been described except for those in the lowland Mosses, which, as they are mainly peat soils, were classified by features of botanical composition and genetic development. (Hall.)

Derbyshire

Sheet 125 (Derby)

Surveying was concentrated on the southern part of the Derbyshire coalfield between the Derwent and Erewash. The established series Kirkby Overblow, Seacroft and Hazelwood are found on the bold escarpments of the Millstone Grit, east of the Derwent. A fairly large area of podzol soils occurs on Breadsall Moors. Between Chaddesden and Milford considerable areas of heavy drift give rise to poorly or very poorly drained silty or fine sandy clay loams with characteristic intense mottling and concretions in the subsoil. The northernmost extent of the Trias formation is marked by the faulted escarpment of Bunter sandstone where soils of the Bridgnorth and Hodnet series occur.

The soils of the Coal Measures appear to be fairly simply related

to each other. Sandstone ridges yield fine sandy loams that become deeper away from the crest. Sand that has been washed down gives poorly or very poorly drained sandy clay loams over a characteristic grey clay with yellow mottling, but without such sand a shallow clay loam over the mottled clay becomes dominant. (Bridges.)

Shropshire

Sheet 166 (Church Stretton)

There now remain only about 30 sq. miles to be surveyed. Soils on the tills and associated drifts of Apedale, of the Onny and Quinney brooks, were mapped, together with those west of the Longmynd in the valley of the East Onny and its tributaries. Most of the till areas have an intricate pattern of gleyed and slightly gleyed soils, analogous to those on boulder clay and glacial gravel as described in the Wem memoir. The East Onny district consists almost entirely of gleyed soils, the development of which was directly linked with a serious regional drainage problem.

Mapping of the Longmynd was extended to the west and north edges of the sheet, where freely drained and slightly podzolized, coarse-textured soils predominate.

Geological complexities and physical difficulties made progress slow around Hopesay and Clungunford, but this district was completed in the late summer. (Mackney and Burnham.)

Cambridgeshire

Sheets 188 (Cambridge) and 173 (Ely)

One surveyor was absent for most of the field season, so that mapping was restricted to completing and checking some boundaries on Sheet 188 as well as sampling further profiles for inclusion in the memoir which is being written. A number of thin-sections were made to examine the micromorphology of the textural B horizons of soils resembling sols lessivés.

Mapping was continued on Sheet 173 in the neighbourhood of Southey, Haddenham, Littleport, Stuntney and Isleham, where peat soils of variable depth or peat soils overlying fen clay and occasional areas of the Isleham or Peacock series were recorded. (Hodge and Seale.)

Buckinghamshire and Bedfordshire

Sheet 220 (Leighton Buzzard)

Mapping was extended into the country between Lidlington and Leighton Buzzard and into the parishes of Shenley Brook End, Woughton-on-the-Green and Silsoe.

The soils encountered are similar to those reported previously. Sandy brown earths are widespread between Ampthill and Boughton End and also occur in the north-west of Woburn Park and north-east of Bragenham; a gravelly phase has been noted around Steppingley and Stockgrove. Podzolized soils are quite well developed on Rammamere Heath and Cooper's Hill.

Gley soils are very extensive, being developed chiefly on the Chalky-Jurassic Boulder Clay. North-west of Bletchley they conform closely to the Hanslope series, but farther east, between Boughton End and Milton Bryan, the profiles are more distinctly mottled to within a few inches of the surface, are generally slightly less calcareous and often have a sandy clay loam or clay loam plough layer. At Silsoe considerable areas of soils of the Wicken series are developed on resorted Gault. (King.)

Hertfordshire

Sheet 239 (Hertford)

Boulder clay, occupying the undulating interfluves in the north-east give rise mainly to calcareous gley soils, but farther west, around Bramfield, soils are more diverse and the commonest may be non-calcareous to 30 inches and is a gleyed brown earth of high base status. In both district fluvio-glacial gravel yields freely drained soils, and on slopes below the spread of boulder clay a complex of freely drained stony, brown earths of medium texture has been distinguished.

South-east of Hatfield soils similar to those around Bramfield on boulder clay overlying London Clay were mapped at elevations from 200 to 400 feet. In addition, a flinty, non-calcareous, strongly mottled drift of fine texture gives rise to gleyed brown earths and, in places, to podzolized soils. This deposit, of uncertain origin, rests on the Pebble Gravel and has been proved to 8 feet without reaching a calcareous zone, but the glacial erratics in it are similar to those in the boulder clay. On the upper slopes of valleys cut into the underlying London Clay, the Pebble Gravel gives rise to a complex of sandy and pebbly soils, among which a coarse sandy, gley podzol is commonest. On the lower slopes are acid, strongly gleyed soils. (Thomasson.)

Glamorgan

Sheet 262 (Bridgend)

Past sporadic small-scale mapping of parts of this and the adjoining sheets has led to the naming of several series, some of which could possibly be correlated with those now being mapped elsewhere. Field examination of soils on Carboniferous Limestone and Lower Lias interbedded shales and limestones at other centres revealed the possibility of correlating some with similar soils in South Wales. Furthermore, field investigations and mineralogical studies suggest that ambiguity in some previously named series mapped on glacial gravels can be removed and further simplification introduced. Numerous profiles were dug in this re-examination which will be continued with further mapping. (Crampton.)

Somerset

Sheets 279 (Weston-super-Mare) and 280 (Wells)

Profiles were sampled to establish the identity of certain parent materials on and around the Mendips, because soils very like those

of the Nordrach series over Carboniferous Limestone occur over rocks of other formations, e.g., Old Red Sandstone and Lower Lias; generally the finer-textured subsoils over these less pervious rocks are mottled and contain abundant manganese dioxide, indicative of imperfect drainage. On lower ground near the Mendips and Quantocks, deep sections in gravelly " Head " with included pockets of stoneless sand of considerable depth provide evidence for the development of texture profiles.

In the moorland around Godney 5 feet of peat has accumulated since the deposition of the estuarine alluvium in Romano-British times. Phragmites peat passes upwards into late Fen-stage Phragmites-Sedge peat and although no oligotrophic plant remains have been found, quite acid peat (pH about 4·5) has developed, possibly as a result of drainage. (Findlay and Clayden.)

Kent

Sheet 305 (*Folkestone*)

Revision and more detailed survey was continued of many parts where complicated soil patterns were indicated in the initial reconnaissance. Some very detailed mapping was done where little or no relief is present to differentiate soil zones that appear as long, sinuous fingers or as islands.

Discrete areas of soils that are distinctly different as regards the extent to which calcium carbonate has been leached are still being found, and some difficulty has arisen where no clear-cut division can be made between them. (Green and Hodgson.)

Other Work

Apart from the primary survey, members of the staff examined many small areas in detail. These include experimental husbandry farms, experimental sites, farm institutes, open-cast coal sites, forestry areas and town-planning areas. In the laboratory, apart from the routine analyses of soils, a promising study is being made of a new potentiometric method of determining the sodium content of saline soils. It has so far been used on soil/water extracts and on saturated soil pastes; pH control is essential to attain the necessary accuracy.

The cartographic section, in addition to preparing the soil maps for publication, prepares all figures and diagrams for Survey memoirs and helps other departments when possible.

SOME ASPECTS OF SOIL MINERALOGY

By

I. Stephen

According to Robinson (1949) " soil may be conveniently considered as being composed of a relatively inert framework of unweathered minerals, together with the so-called clay–humus complex, consisting mainly of the products of the chemical weathering of silicates and with humus, which is the product of the decay of plant and animal residues in the soil ". The mineral matter of soils consists of particles of all sizes which, for the purposes of describing the mechanical composition, are conventionally divided into four grades: coarse sand from 2 to 0·2 mm.; fine sand from 0·2 to 0·02 (or 0·05) mm.; silt from 0·02 (0·05) to 0·002 mm.; and clay below 0·002 mm. The sand and silt fractions may be ordinarily regarded as the " relatively inert framework ", while the clay is the more reactive part of the soil and is the main seat of the property of base-exchange as well as being largely responsible for the mechanical properties. Primary mineral grains, such as quartz, feldspars, micas, amphiboles, pyroxenes, iron oxides and various accessories, normally constitute the bulk of the sands and silts, although occasionally secondary products of weathering, including concretionary material, may be present. The clay fraction may contain grains of quartz and other resistant primary minerals, but most of it consists of material of secondary origin in the colloidal state which has been formed by the processes of weathering of primary minerals, either in the present environment or during previous cycles of weathering and sedimentation.

Methods for identifying the minerals in soils follow the lines normally used in studies in sedimentary petrography. Because of their amenability to study by the petrological microscope, the coarser material in soils received most attention by earlier workers in soil mineralogy, and much of that work was concerned with identifying the minerals in the fine sand fractions to correlate drifts with geological formations with a view to parent material classification (Hendrick and Ogg, 1916; Hendrick and Newlands, 1923, 1925; Hart, 1929a, b). The constitution of the clay fraction was largely ignored, because suitable techniques for its study were lacking. The applicability of X-ray diffraction to the problem of determining the constitution of fine-grained materials was demonstrated by Hadding (1923) and Rinne (1924), and using this method Hendricks and Fry (1930) and Kelley *et al.* (1931), working independently, showed that the colloidal fractions separated from some selected soils in the U.S.A. contained crystalline particles comparable with those of the layer lattice silicates montmorillonite–beidellite and halloysite. Since then much work has been done on the occurrence of clay minerals in soils, and other techniques employed for their

characterization include differential thermal analyses, cation exchange reactions, electron microscopy and infra-red spectrometry.

Pedogenic weathering

Not many detailed studies have been made of the changes undergone by rocks and minerals in the course of disintegration and decomposition into clay. It is now realized that all the classical soil-forming factors (parent material, climate, time, topography and biotic agencies) have their influence on the processes of weathering, and consequently on the minerals present in soil colloids, and to assess the importance of the different factors the weathering products of different rock types must be compared under similar environments, and *vice versa*.

Several studies of rock weathering of this kind have been made at Rothamsted. One area studied was the Malvern Hills in the west of England, where the suite of rocks shows great variation from acidic rocks (granite) to highly basic rocks rich either in biotite (biotitite) or in hornblende (appinite): furthermore, there is no glacial or other drift to introduce ambiguities in the relationship of bedrock and soil (Stephen, 1952a, b). The mineralogical composition of the soils was determined by the constitution of the underlying rocks, both as regards the coarser " inherited " particles and the clays. In the sands, quartz and feldspar were the principal minerals in the granite-derived soils, whereas in the soils derived from the basic rocks amphiboles, epidote-clinozoisite and iron oxides occurred in fairly large amounts; the soil derived from the biotitite also contained characteristic yellowish brown glistening flakes of vermiculite. Illite (dioctahedral mica) * was dominant in the clays of the granite-derived soils, and trioctahedral chlorite–vermiculite in those derived from the basic rocks; the presence of these minerals was directly related to the trend of alteration of the primary minerals in the different rock types. The illite appears to be derived exclusively from the breakdown of feldspar in which abundant white mica is developed as hydrothermal inclusions. The operation of the weathering sequence (biotite, hornblende) —→ chlorite —→ vermiculite appears to be the conditioning factor leading to the development of the soil clays derived from the basic rocks. Pseudomorphing of original biotite by chlorite in the biotitite, and the development of finely crystalline secondary chlorite at the expense of hornblende in the appinite, was observed in thin sections of the weathered rocks, and further weathering of the chlorite from either source through intermediate stages of mixed chlorite–vermiculite produces vermiculite in the soils. The occurrence in the clays of illite and chlorite, which are early members of the layer lattice silicates in the sequence of weathering proposed by Jackson *et al.* (1948), and the presence of much unweathered (though readily weatherable) minerals in the sand fractions, leads to the conclusion that the soils are at an early stage of development.

The association of acid and basic rocks, as described above, is

* The terms tri- and dioctahedral were proposed by Stevens (1946), the former to designate layer lattice minerals in which all three octahedral positions are occupied, and the latter for those in which one in three octahedral positions is vacant.

common in many regions of igneous intrusion and metamorphism, and a comparative study of two profiles from Ghana, occurring only a few miles apart under similar environments, on two such contrasted rock types (a feldspar–quartz–schist and a hornblende–garnet–gneiss) has shown that, even under the more extreme climatic conditions there, the nature of the parent rock was strongly reflected in the constitution and also the morphology of the derived soils (Stephen, 1953). The acid schist gives a grey quartzose sandy soil containing kaolin–montmorillonite clay, whereas the soil derived from the basic gneiss has the characteristics of a typical tropical black earth (regur) with almost exclusively montmorillonite clay. The more complete weathering of the soils, compared with those on the Malvern Hills, is indicated by the lack of ferromagnesian minerals (amphiboles, pyroxenes) and feldspars in the surface horizons, although these are abundant constituents of the parent rocks.

The degree of crystallinity of rocks may also affect the products of weathering (Muir, 1951). In a soil developed from a holocrystalline olivine-basalt in Syria, the clay was dominantly kaolin, whereas a merocrystalline olivine-basalt with over 70 per cent glass in the ground mass altered to montmorillonite. The two also differed in chemical composition, particularly in the Ca/Mg and Ca/Sr ratios in their exchange-complex.

The probability of drainage conditions influencing the clay minerals in soils was indicated by Nagelschmidt *et al.* (1940), working on Indian soils, and the combined influence of drainage and parent material has been established by Mitchell (1955) for some Scottish soils. Soils developed on drift derived from granite and various metamorphic and sedimentary rocks (quartz–schist, quartzite, Dalradian slates, Old Red Sandstone, etc.) contain illite as the major clay mineral, whereas in those developed on drift from basic igneous source rocks vermiculite or montmorillonite is dominant. The influence of drainage is pronounced in these latter soils, vermiculite tending to prevail in the brown earths with free drainage, and montmorillonite in the gley soils. The same relationship between the production of vermiculite or montmorillonite and drainage conditions in soils derived from basic rocks was also reported by Butler (1953) for soils overlying serpentine in the Lizard area of Cornwall, and by McAleese and Mitchell (1958) for soils derived from basaltic parent material in Northern Ireland.

The great influence of the parent material on the products of weathering is evident in the studies mentioned above, which are mainly confined to temperate regions; but where weathering is intense and prolonged, as under tropical and subtropical conditions, its influence may be greatly lessened or even eliminated. For example, in some parts of Tanganyika, where wet and dry seasons with high temperatures alternate, both acid and basic gneisses give rise to red earths with dominantly kaolinitic clays (Anderson, 1957; Muir *et al.*, 1957). Except where these soils are shallow, only minor amounts of feldspars, ferromagnesian and other primary minerals are present, and it appears that they weather directly to kaolinite, mica and iron oxides; consequently, as stated by Muir *et al.*, " it is only by an examination of the resistant heavy minerals that an indication of the probable source rocks is obtained ".

Weathering of individual minerals has been much studied; much of this work has concerned the micas, as, in addition to being widely distributed in soils, they are potential sources of potassium available to plants. From these studies the process of vermiculitization in the weathering of primary biotite (trioctahedral mica) appears to be common. The vermiculite is formed either *via* mixed-layer biotite–vermiculite intermediate products (Wager, 1945; Walker, 1949; Butler, 1953, 1954) or *via* mixed-layer biotite–chlorite and chlorite–vermiculite products (Stephen, 1952a; Butler, 1953). The most pronounced chemical changes occurring during the weathering of biotite to the expanded-lattice mineral are: loss of potash and magnesia, gain of silica and water, almost complete oxidation of iron and a large increase in cation-exchange capacity. Fewer studies have been made on the weathering of the dioctahedral mica muscovite. A comparative study of muscovite from adamellite and the overlying soil in Cornwall showed that, although structural changes were slight and flakes from both environments gave visually identical X-ray patterns, the loss on ignition from the soil muscovite was greater than from the fresh mineral, and the potash content had decreased (Butler, 1953). The excess of water and deficiency in potash in hydrous micas compared with normal micas can be explained on the basis of substitution of oxonium ions (H_3O^+) for potassium in the interlayer positions (Brown and Norrish, 1952).

The occurrence of a mineral which appears to be the dioctahedral analogue of vermiculite was described by Brown (1953, 1954a) in the clays of some gleyed soils developed on Carboniferous till in Lancashire. It is apparently the weathering product of an aluminous mica, as it is dominant in the upper more highly weathered layers, where it replaces dioctahedral hydrous mica, the chief clay component in the lower layers. A similar antipathetic relation with depth between mica and vermiculite occurs in some soils from Anglesey (Muir, 1958), e.g., in the Treuddyn series, a brown earth of low base status developed in drift of Millstone Grit and Mona Complex origin, and in the Dyfnan series, a non-calcareous gley soil derived from drift from Carboniferous shale and limestone.

	% K_2O in clay	% mica in clay	% vermiculite in clay
Treuddyn series			
0–5 inches	1·59	20	45
28–36 inches	4·34	65	Nil
Dyfnan series			
0–7 inches	0·70	Trace	75
14–23 inches	2·71	60	15

The increase in vermiculite at the expense of mica in the surface horizons, together with a decrease in the potash content, suggests that the vermiculite originates by loss of potassium from the mica.

That the degree of alteration of the mica lattice may be important in agronomic practices has been demonstrated by Brown (1954b) for some Irish soil clays. The clay minerals present in the soils were illite (mica), vermiculite, chlorite, kaolin and a material provisionally called " degrading illite ". All the soils that, in field experiments, fix potash contained " degrading illite ", whereas the

others did not, and the " degrading illite " may either fix potassium or be related to the actual cause of fixation.

Study of the detrital minerals

The mineralogical examination of the sands and silts is greatly facilitated by dividing them into fractions according to specific gravity. This is done by separation in a liquid of high specific gravity, e.g., bromoform (S.G. 2.90). The heavy fraction (S.G. > 2.90) includes the ferromagnesian and related minerals, iron oxides, and various stable accessory minerals such as zircon, tourmaline, rutile, anatase and garnet. Although in immature soils derived from igneous and metamorphic rocks rich in ferromagnesian minerals the amount of " heavy residue " may be 50 per cent or greater, in sediments and derived soils it is often less than 1 per cent, but may contain a wide variety of mineral species, 15–20 being common. These minerals are particularly suitable for purposes of correlation and differentiation, because distinctive associations of minerals are characteristic of different rock types and stratigraphic units. Undoubtedly the most important roles of heavy mineral analyses in pedological studies are in determining the sedentary nature (or otherwise) and the degree of uniformity of the materials comprising the solum, and thus in deciding how far vertical variations reflect pedogenic processes or are geologic in character caused by parent material or depositional differences.

Often a cursory examination of the residues will determine whether or not a soil is derived *in toto* from the underlying formation, as shown by Stephen *et al.* (1956) in a study of tropical black clays with gilgai in Kenya. The soils occur on the Athi Plains to the east of Nairobi, and are underlain by volcanic rocks of trachytic affinities. On the east the plains are bounded by hills of Basement Complex, which contains a wide variety of metamorphic rock types. An examination of the heavy residues of the sands from the soils showed that they could not be entirely derived from the underlying volcanic rocks, as minerals occurring in the lavas and species such as sillimanite, kyanite and staurolite were present in all horizons. The latter are characteristic of metamorphic rocks, and their presence suggested that Basement Complex material had been deposited on the soils possibly by wind transportation during dry Interpluvial periods. These additions then became incorporated in the soils by the churning action resulting from their shrinking and cracking properties.

Studies of " chalk heath " soils on the South Downs and of soils overlying serpentine in Cornwall by Perrin (1956) and Coombe and Frost (1956), respectively, showed that the mineralogical composition of the soils is inconsistent with derivation from the underlying rocks. On the basis of particle-size distribution analyses, they postulated substantial loessial accessions to the soils. Perrin further points out that deposits of a well-graded nature with a maximum particle-size distribution in the silt grade (0·04–0·03 mm.), also considered to be loess-like in character, occur overlying Chalk on the Berkshire Downs, the Carboniferous limestone in Derbyshire and the Clay-with-flints on the Chilterns. Where undisturbed by recent erosion, the superficial layers of both plateau and valley drifts on

the Chilterns are rich in silt and overlie more clayey subsoil horizons; the non-clay fraction of these subsoil horizons may also be considerably coarser in texture than in the surface layers (Avery, 1958). Although the silty character of the surface soils and the increased clay content of the subsoil could be attributed to pedogenic processes—such as the physical disintegration of sand grains *in situ* to yield silt-sized particles by a mechanism such as frost shattering combined with clay-eluviation from or clay-decomposition in the A-horizons—mineralogical studies indicate that parent material differences are also involved (Stephen, 1957; Loveday, 1958). Soils studied in detail included profiles of the Batcombe series, as mapped by the Soil Survey of England and Wales, which is developed over Clay-with-flints that probably consists largely of the weathered remains of Chalk and Eocene sediments redistributed by ice-action or solifluxion. In these profiles, occurring on level or gently sloping plateau sites where the drift is thick, thin sections show that some physical disintegration of sand grains has taken place and also provide evidence of clay migration and deposition in the heavier-textured B-horizons. In all the profiles studied, however, the coarse silt (0·05–0·02 mm.), and, to a lesser extent, the fine sand (0·2–0·05 mm.) of the surface layers contain heavy residues of a different mineralogical character, and therefore different origin, from that of the subsoil horizons. Non-opaque heavy minerals common to all horizons are zircon, rutile, tourmaline, kyanite and staurolite, but the surface horizons contain a more varied suite, including epidote-clinozoisite, garnet, chlorite and green hornblende, which are rare or absent in the substrata. The mineralogical evidence in conjunction with particle-size distribution studies strongly suggests a loessial origin for a major portion of the silt, and the added wind-blown materials seem to have been incorporated with the underlying drift by solifluxion either during or after their deposition. These profiles have therefore developed in materials of different geologic origin and character and the pedogenic processes have further accentuated the differences.

As well as the fairly widely separated loess-like deposits discussed above, undoubted loess of considerable thickness at Pegwell Bay in Kent has been described by Pitcher, Shearman and Pugh (1954). Such deposits may, therefore, be more widespread than was formerly supposed and they may constitute or contribute to the upper layers of soils over considerable areas in Southern England. One of the areas at present being investigated is the Mendip Hills in Somerset, where it is uncertain whether the soils overlying the Carboniferous limestone are residual or whether they are partly derived from superficial deposits of different origin. These soils have maximum particle-size distributions in the range 0·06–0·02 mm., which has led to the suggestion that they have developed in part in a loessial cover overlying the limestone (Findlay and Clayden, 1958). The insoluble residues from the limestones, however, have a very similar mechanical composition, so it appears that the resolution of the problem will depend on mineralogical evidence, using criteria similar to those advocated by Smithson (1953) to recognise residual soils on Carboniferous limestone in North Wales. After a mineralogical examination of the residues from the limestone the criteria

suggested were that the light fraction of the soils should be dominated by quartz euhedra and chert rather than detrital quartz grains, and that the heavy fraction should be small in amount and poor in mineral species. The cover in North Wales is strongly influenced by mixed drift of northern origin, and the limestone may have contributed little to the constitution of the overlying soils but acts rather as " a foster-parent that has imparted to the profile the characteristics of a limestone soil ".

Although normally constituting 95 per cent or more of the sands and silts of soils, the light minerals (S.G. $< 2{\cdot}90$) do not usually receive as much attention as the heavy minerals. In many soils the light fraction is dominated by quartz and contains only few other mineral species, thus making the assemblages less valuable than the heavy residues for purposes of correlation. A study of the light minerals, however, should not be neglected, as the separates often possess features worth attention. Various forms of silica occurring in soils have been described by Smithson (1956), who, besides drawing attention to varieties of quartz and chalcedony, described and depicted characteristically shaped grains of opaline silica occurring in the silts of various British soils. These originate from organic matter, being components of grass leaves, and he suggested that a study of such phytoliths might provide information about the former vegetation and soil conditions of the sites where they occur. Phytoliths derived from *Nardus stricta* have unmistakably characteristic forms, but the shapes of others can only be assigned to tribes of grasses (Smithson, 1958). The presence of phytoliths in palaeosols in Illinois has been noted by Beavers and Stephen (1958), indicating the possibility that they could be used to determine the presence and location of buried A-horizons. The opal phytoliths in some of the palaeosols had been transformed to chalcedony.

An unusual form of chalcedony in soils developed on Clay-with-flints and allied deposits has been reported by Brown and Ollier (1957). The grains, apparently of inorganic origin, occur in a variety of forms ranging from bundles of parallel rods arranged in tabular form to grains with a botryoidal or honeycombed appearance. As silica is considered to be more mobile under tropical conditions, a warmer climate of the past may have promoted their formation. Some support for this hypothesis is given by a consideration of the morphology of the plateau drifts (Avery, 1958). A characteristic feature of these is the incorporation of " relic " soil materials of a braunlehm character with red mottling (rubefication), which according to Kubiëna (1956) occurs in strongly alternating wet–dry regimes of the tropics.

Feldspars also occur in the light fractions of all but the most highly weathered soils and, as specific types of feldspar are typical of different groups of igneous and metamorphic rocks, a study of the variety present may be useful in determining the source of soil materials derived from such rocks (e.g., Muir and Stephen, 1957). As sodic plagioclases are more resistant to weathering than the calcic plagioclases, Graham (1949) has suggested that the Na/Ca ratios of the sands and silts could be used to assess the degree of weathering undergone by soils; and Hawkins and Graham (1950), studying silt separates from the A-horizons of some Missouri soils, showed that

the percentages of potash feldspar and plagioclase were in direct proportion to the fertility levels measured by field tests. The relation between the feldspar content and the agronomic potential of soils has also been demonstrated by other workers (e.g., Leenheer, 1950a, b; Jeffries *et al.*, 1953; Jeffries *et al.*, 1956). Other minerals that frequently occur in the light separates are weathered micas, glauconite, calcite and gypsum; these are diagnostic of either derivation from particular types of source rocks or of characteristic weathering regimes.

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THE USE OF INSECTICIDAL SEED DRESSINGS

By

M. J. Way

Jameson, Thomas and Woodward (1947) showed that the chlorinated hydrocarbon insecticide γ-BHC applied as a seed dressing at about 0·02 mg./seed could protect the young cereal plant from wireworm attack. This was a most important step in insect pest control of agricultural crops, for it has led to widespread use of insecticide seed dressings against many insect pests, mainly soil insects, including, in Britain, wireworms (*Agriotes* spp.), flea beetles (*Phyllotreta* spp.), wheat-bulb fly (*Leptohylemyia coarctata* Fall.), and onion fly (*Delia antiqua* Meig.). The minute amounts of insecticide used, sometimes as little as 1 oz./acre, avoid undesirable effects such as destroying beneficial soil insects and the accumulation of residues liable to harm the plant or affect its flavour and food value. Cost is small, especially as no extra machinery or labour is needed to apply the insecticide in the field.

At about the time that the chlorinated hydrocarbon insecticides, γ-BHC, dieldrin, aldrin and heptachlor were being developed as seed dressings against soil insects, some organic phosphorus compounds taken up by roots and seed were shown to move throughout the plant and to kill insects feeding on aerial parts of the plant by their "systemic" action. (Schrader, 1951; Ivy, Iglinsky and Rainwater, 1950; Ripper, Greenslade and Hartley, 1950; Jancke, 1951; David and Gardiner, 1951, 1955.) Some systemic phosphorus insecticides, notably demeton and demeton-methyl, have since proved especially valuable as aerial sprays against aphids (Way, Smith and Potter, 1954; Way, Bardner, Aitkenhead and Van Baer, 1958; Broadbent, Burt and Heathcote, 1956; Hull, 1958), but until recently their use as seed dressings has not been examined in detail with field crops. The systemic phosphorus insecticides yet tested have not been very effective against soil insects (Bardner, 1958; Walker, 1958); conversely, except for γ-BHC (Starnes, 1950; Shapiro, 1951; Ehrenhardt, 1954; Bradbury and Whitaker, 1956; Jameson, 1958), the chlorinated hydrocarbons have had little systemic activity against insects attacking aerial parts of the plant. Thus, they may be conveniently considered separately. All work on insecticide seed dressings cannot be covered in this review and as seed dressing with chlorinated hydrocarbons is now well established in practice, it is appropriate to discuss mainly their limitations which have led to the recent work at Rothamsted on mode of action and on methods of application. Phosphorus insecticide seed dressings have been used only experimentally except with cotton; results will therefore be given mainly to show where they are likely to prove useful.

Wireworm control

Since it was first demonstrated that γ-BHC seed dressing could protect young cereals from wireworm attack, much work has been done on wireworm control by γ-BHC, aldrin, dieldrin and heptachlor seed dressings especially in North America. Some of this is reviewed by Lilly (1956), Potter, Healy and Raw (1956) and Raw and Potter (1958). Seed dressings have usually protected various seedling crops in the year of application, but there is conflicting evidence about their ability to lower the wireworm population. Potter, Healy and Raw (1956) and Raw and Potter (1958) have made a special study of this problem. In one experiment a seed dressing of 1·2 oz. γ-BHC/acre on wheat sown in November 1947 was compared with soil treatments where the insecticide was combine drilled at 6 oz. γ-BHC and broadcast at 1 lb. γ-BHC/acre. Grain yields in 1948 were respectively 24·0, 24·8 and 30·6 cwt./acre compared with 8·9 in untreated plots. The plots were redrilled with wheat in the autumn of 1948 without further insecticide treatment, and in 1949 yielded 24·2, 37·3 and 39·6 cwt./acre, the yield of the untreated being 28·4. The seed dressing therefore gave a good response in yield, but less than the soil treatments, and unlike these it had no effect on the subsequent crop. The second-year wireworm populations (numbers per plot, square root transformation) were: untreated, 3·30; seed dressing, 3·73; combine-drill, 2·20; broadcast, 1·33, showing that the seed dressing did not kill the wireworms. Presumably it deters them from feeding during early stages of growth when the young plant is especially susceptible, and this would decrease losses of crop when the infestation is small. With large infestations, however, attack at a later stage of growth when the deterrent effect has worn off and when the plant would normally be able to withstand moderate damage, could be harmful, and this may explain why a γ-BHC seed dressing has sometimes failed to protect a crop against large wireworm populations (Dogger and Lilly, 1949; Kulash, 1953). There are, however, further difficulties in our understanding of how seed dressings act against wireworms, for a seed dressing sometimes kills wireworms—for example, in experiments by Lange, Carlson and Leach (1949), 70–95 per cent of wireworms in the immediate area of the treated seed were killed, and the total population was reduced by about 50 per cent. These, and similar results of Starks and Lilly (1955), were obtained in experiments with late-sown crops, when the wireworms were immediately attracted to the ungerminated or newly germinated seed, in contrast to the conditions studied by Potter, Healy and Raw, in which the crop was sown about 4 months before the wireworms became active; by then the growing seedling would have long since exhausted the seed, and the wireworms would attack the shoot. Therefore, wireworms attacking the ungerminated or newly germinated seed may be either deterred (Long and Lilly, 1958) or killed by contact with the insecticide seed dressing, whereas in attacking the older plant they are unlikely to be killed, but may be deterred by systemic action of insecticide translocated to the shoot. This confirms the general conclusion that seed dressings as used at present against wireworms

become less effective as the plants age (Kulash and Munroe, 1955); also, that they must be regarded as methods of obtaining temporary protection and note as a means of destroying the wireworm population in the field (Lange, Carlson and Leach, 1949). It seems certain, however, that seed dressings are not yet being used to the best advantage against wireworms; for example, it would be valuable to know more about their mode of action and to study methods of increasing the dose of insecticide on the seed to levels approaching those which have been successfully applied by combine-drill or as a broadcast treatment.

Mode of action of seed dressings against certain Diptera

A wireworm may spend 5 years in the soil before pupating, and populations of overlapping generations can persist many years feeding on the underground parts of many plant species. By contrast, the larvae of soil-inhabiting species of Anthomyidae and Chloropidae (Diptera) normally pupate within 2–8 weeks of hatching; they are mostly specific in their choice of plant hosts, and they usually appear only after the host has been planted. Unlike wireworms, they would soon die if deterred by a seed dressing, not only from lack of alternative wild hosts, but also because they attack the plant as newly hatched larvae which cannot survive without food. It seems their control ought to be simpler than that of wireworms, but in practice the effectiveness of the seed dressings differs greatly with different insect species. A dieldrin seed dressing, for example, can almost completely protect the young onion crop from damage by the larval onion fly, *Delia antiqua* Meig.; it will kill the larva of the closely related wheat-bulb fly, *Leptohylemyia coarctata* Fall., but does not prevent the plant from being damaged; finally, it usually has little or no effect on the larval frit fly, *Oscinella frit* L. Chloropidae.

Way (1950a, 1959b) studied the mode of action of the seed dressings in an attempt to find the circumstances that effect their action against the three species. The simplest and most effective way in which a seed dressing can act is by direct contact with the insect before it attacks the plant. For this to happen, the larva must pass close to the treated seed; therefore, much depends on the position of the eggs and on the behaviour of the newly hatched larva.

Onion-fly eggs are laid on the soil surface close to the plant, but even when the seed was sown 1 inch deep, most of the larvae crawled down to enter the plant at the base of the bulb close to the position of the treated seed. The normal behaviour of newly hatched onion-fly larvae seems to ensure that almost all are killed by contact action before they can damage the plant. This was confirmed by preliminary experiments which showed the onion seedlings, replanted after removal of the dieldrin-treated seed, were no longer protected from onion-fly attack (Way 1959a).

Frit-fly eggs are laid both on the plant and in the soil. Larvae hatching from the former can enter the oat or wheat shoot from within the ensheathing coleoptile and sometimes above soil level. In these circumstances, kill by direct contact with the seed dressing seems unlikely. Larvae hatching from eggs in the soil normally reach and enter the shoot above the seed at, or just below, soil level and thus are unlikely to meet the insecticide unless the seed is shallow

sown (Way 1959b). Experimental results have confirmed these conclusions: when dieldrin-dressed wheat seed was sown at three depths—just below the soil surface, at ¼ inch and at 1 inch, the percentages of shoots damaged by frit larvae were 17, 29 and 41 respectively for treated, and 40, 47 and 50 for equivalent untreated control plants. The mean numbers of larvae per plant were 0·3, 0·6 and 0·7 for treated seed and 1·0 for all sowing depths of the untreated. Larvae from eggs in the plant probably formed the majority of the survivors of the shallow-sown treatments. Unfortunately, it is not normally practicable to sow oats or wheat less than about 1 inch deep; hence, the lack of protection from dieldrin seed dressings in practice.

The wheat-bulb fly is unusual because its eggs are laid in August and September well before the host plant, winter wheat, is drilled. The eggs are distributed in the soil by cultivations to a depth of 8 inches or more, and eventually hatch in the following February–March. The newly hatched larvae move upwards, and most reach the surface soil, where they search for the young wheat plant. Therefore, irrespective of the position of the eggs, they mostly behave like onion and frit-fly larvae and reach the plant from near the soil surface. The shoot is entered at a depth of about ¼–1 inch, suggesting that, as with frit-fly larvae, contact action is unlikely unless the seed is shallow sown. This was confirmed by experiments with dieldrin seed dressings, where the calculated kill, probably by direct contact, varied from 0 per cent for a 3 inch sowing depth to 45 per cent at ½ inch (Way 1959a). Experiments in which seedlings were replanted and infested after removing the treated seed, confirmed that the latter was needed to protect the plant from attack.

Thus the contact action of the seed dressing may depend on at least three biological factors: the behaviour of the newly hatched larva (onion, frit and wheat-bulb fly), the position of the seed (frit and wheat-bulb fly) and the position of the egg (frit fly).

Apart from direct contact with the treated seed, the larva may be affected outside the plant by fumigant action and by insecticide picked up by tips of roots and shoots as they emerge from the germinating seed. More important, however, is the possibility that chlorinated hydrocarbon insecticides can act systemically. γ-BHC is taken up by the plant, and it has already been suggested that wireworms are deterred by insecticide translocated from the seed to the underground parts of the shoot. Furthermore, Gough and Woods (1954) found that larvae of wheat-bulb fly may die after feeding inside wheat shoots growing from dieldrin-treated seed. Experiments in which larvae died after feeding on pieces of shoot, no part of which could have come into contact with the seed dressing, show that the kill is by systemic action (Way, 1959a). This property has made dieldrin, aldrin and heptachlor seed dressings the recommended control measure for wheat-bulb fly, for although the larva usually destroys the first shoot, it is killed before destroying any more. The action of γ-BHC seed dressing is less clear; γ-BHC appears to be absorbed and lost by the plant more readily than the other chlorinated hydrocarbons. In the very young seedling, therefore, the higher concentration in the plant, and perhaps

inherently greater toxicity, ensures that the wheat-bulb fly larva is usually either killed or deterred before it causes serious damage. The insecticide is then quickly lost, perhaps mainly by volatilization (Bradbury and Whitaker, 1956) at a stage when dieldrin, for example, is still present in lethal concentration in the shoot.

It is surprising that, although systemic action is particularly important for wheat-bulb-fly control and probably in protection from wireworm damage, there is little evidence that either frit- or onion-fly larvae are affected in this way by chlorinated hydrocarbon seed dressings. For example, in experiments with frit fly using dieldrin-dressed seed, the number of dead larvae found in treated plants and the proportion of larvae which survived to become pupae were the same as in untreated plants (Way, 1959b). Systemic action may depend on a delicate balance between uptake and loss of insecticide that is influenced especially by temperature; this would increase loss from dilution by plant growth and by volatilization in late May and June, when frit- and onion-fly larvae are hatching, above that in the colder weather of March to early April when wheat-bulb-fly larvae and wireworms are active.

The importance of placement of insecticide around the seed

Way (1959a) showed that, although dieldrin and aldrin need to be placed in contact with either the shoot, roots or seed of the wheat seedling to act systemically against wheat-bulb fly, contact between the insecticide and the seed seemed particularly important. For example, when wheat seeds were planted together in pairs, one dead and one alive, with either the dead or the live seed dressed with dieldrin, contact action killed as many larvae whether the live or dead seed had been treated, whereas systemic action killed a calculated 50 per cent of the larvae when the live seed was treated and only 18 per cent when the dead seed was treated. The value of applying the insecticide to the seed was also convincingly shown by Bardner (1959a), in field trials when aldrin, dieldrin and heptachlor dressings at 3 oz. active ingredient/acre controlled wheat-bulb fly better than aldrin or dieldrin combine drilled at 24 oz./acre. Further, in the control of the aphid, *Myzus persicae* Sulz. on potatoes, Burt (1959) showed that the effect of spot treatments of the systemic phosphorus insecticide " Thimet " lessened as the insecticide was placed at increasing distance from the " seed " tuber. Seed dressings should therefore be valuable when systemic action is important, and also, as in onion-fly control, when seed treatment concentrates the insecticide where the larva is likely to meet it before attacking the plant. This does not necessarily mean that seed treatment is better for systemic action than other methods of soil application, at any rate where persistence is needed. For example, Burt (see above, p. 128) has shown that " Thimet " combined with the fertilizer protected potatoes from aphids better, and for longer, than the same amount placed under the " seed " tuber. This is probably because lasting protection by systemic phosphorus insecticides depends on their continued uptake by the roots, the absorbing region of which may not only grow beyond the area of the treated seed (Way and Needham, 1957) but also becomes concentrated where the fertilizer is placed (Cooke, 1954).

Seed dressings have lacked persistence partly because the dose of insecticide has been limited to what would adhere as a dry dust to the seed. Bardner (see above, p. 130) has recently studied methods of applying larger doses using different " stickers " and " carriers " to enhance both initial and persistent effects. A methyl cellulose sticker for increasing the dose of dieldrin, aldrin and heptachlor has already given promising results in wheat-bulb-fly control (Bardner, 1959; Way, 1959a). Unfortunately, insecticides, especially γ-BHC and many phosphorus insecticides, are likely to be more phytotoxic as seed dressings at high rates than when applied in other ways, but there is preliminary evidence (p. 130 above) that carriers, such as activated charcoal, and stickers, such as polyvinyl acetate, can release the insecticide comparatively slowly, thereby lessening phytotoxicity and enhancing persistence of systemic action.

Systemic Phosphorus Insecticides

Laboratory work on systemic phosphorus insecticides has mainly demonstrated their uptake and translocation to aerial parts of the plant where they kill various insects. Early work by Andersson and Ossiannilsson (1951) and Ashdown and Cordner (1952) indicated that crops might be protected from aphids by schradan and demeton seed dressings. Using a demeton seed dressing on spring-sown field beans (*Vicia faba*), Way and Needham (1957) found that, although the insecticide protected the seedling shoot from damage by adult pea and bean weevil (*Sitona lineatus* L.), it had little effect on the bean aphid (*Aphis fabae* Scop.) which colonizes the crop 2–4 months after the seed is sown. The aphid was controlled by demeton dust applied to the seed drill at sowing time, but the dose of active ingredient needed was about 180 times more than that required by a suitably timed demeton aerial spray. In an experiment with potatoes, demeton dust put in the planting hole around the " seed " tuber at rates of 0·125–0·25 gm. of active ingredient/tuber, killed the aphid *Myzus persicae* Sulz. for 40–60 days after planting, whereas 0·5–1 gm. per tuber was needed to protect the plant for more than 112 days. Way and Needham concluded that seed dressings of systemic phosphorus insecticides should be valuable for protecting the young plant shoot soon after germination, especially as an aerial spray is not only difficult to apply at the right time but is wasteful and does not persist in the small, rapidly growing shoot.

The young plant is particularly susceptible to viruses; therefore, the initial protection and persistence provided by a systemic insecticide may be useful in preventing early virus transmission by insects. In this connection Burt (see above, p. 128) showed that " Thimet " and " Rogor " at 0·31 and 0·35 gm. active ingredient/potato seed tuber put in the planting hole kept the crop almost completely free from aphids throughout the period when they usually infest it. The rates, like those of demeton used by Way and Needham, were high, but less insecticide might still give the necessary initial protection. Dunning (see above, p. 194) also obtained promising results with seed dressings of " Thimet ", " Disyston " and " Rogor " on sugar beet. These chemicals not only controlled

aphids but also lessened the spread of aphid-transmitted yellows virus in the young plants.

Although demeton as a seed dressing may be slightly better than "Thimet" and "Disyston" against aphids (Reynolds, Fukuto, Metcalf and March, 1957), the last-named chemicals are less specific, and as seed dressings they protect the aerial parts of some young crops from various species of Aleyrodidae, Thysanoptera, Diptera, Lepidoptera and Coleoptera as well as Aphidae. (Reynolds, Fukuto, Metcalf and March, 1957; Parencia, Davis and Cowan, 1957; Dunning (see above, p. 194)). Disadvantages of the systemic phosphorus insecticides are that they can be phytotoxic and they are poisonous to mammals and birds. Evidence so far (Reynolds, Fukuto, Metcalf and March, 1957; Burt (see above, p. 129)) showed that dangerous residues can be avoided in some food plants, and the main problem is the handling of such poisonous chemicals as "Thimet", "Disyston" and demeton as concentrated seed dressings during and after their application to the seed. In this respect "Rogor" is apparently less dangerous and is an advance towards the ideal of the safe systemic phosphorus insecticide which, as a seed dressing, should have many uses in agriculture.

Conclusion

This review has dealt mainly with some of the biological factors that are important in the action of insecticide seed dressings. Little has been said about some other factors that need to be considered before seed dressings can be used to the best advantage, and so that what has been discussed can be put in proper perspective, the main ones are listed below under three main headings. It will be seen that many of the factors are likely to interact.

(1) *The relationship between the seed dressing and the seed*

Something has been said about the special value and limitations of applying insecticides direct to the seed and also about methods of varying the dose, but the safety margin between the dose which is insecticidal and that which is phytotoxic is especially important, because seed dressings are more likely to harm the young plant than are other methods of soil application.

(2) *The fate of the insecticide in the soil and in the plant*

This will influence the immediate and lasting effects of insecticides against insects in the soil and on the plant, and is also relevant to the problem of harmful residues. Soil factors include the spread of insecticide through the soil and its rate of disappearance, especially in relation to soil type and root distribution. Plant factors include rate and period of uptake as well as distribution and disappearance of the insecticide in the plant in relation to plant species and age. Little is known about soil problems, and few plant studies relate directly to the action of seed dressings. They are not discussed in this review.

(3) *The relationship between the insect and the insecticide in the soil and plant*

This involves inherent resistance of the insect, the reaction of the insect to the insecticide and the behaviour of the insect in relation to the plant and to the position of the treated seed. Except for inherent resistance, these problems are discussed in the review.

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THE WOBURN EXPERIMENTAL STATION

H. H. Mann

In the early 'seventies of last century British agriculturists were agitated by changes in the relation between landlord and tenant of farms, first by the Irish Land Act of 1870 and then by the Agricultural Holdings Act of 1875. The second Act made it compulsory to compensate an outgoing tenant for the unexhausted value of foods bought during his tenancy. After discussions on this subject, Sir John Lawes of Rothamsted, whose authority at that time was very great indeed, published a paper on the "Valuation of Unexhausted Manures" in the *Journal of the Royal Agricultural Society* (I) that contained a table purporting to give the estimated money value of the manure obtained from the consumption of 1 ton of each of the commoner farm foods. Farmers, however, at once asked whether the values assigned by Lawes were really true. Does the outgoing tenant get his due, or is the landlord or the incoming tenant over-charged? These questions were raised at a meeting of the Royal Agricultural Society in November 1875, when it was urged that the subject needed settling by direct experiment on different soils and under different conditions.

The then Duke of Bedford (Hastings Russell) offered the use of land on his estate at Woburn and funds to pay the cost of such experiments, provided that the Royal Agricultural Society would direct and manage them. The offer was gratefully accepted, and the Society asked Sir John Lawes and Dr. A. Voelcker (the consulting chemist to the Society) to draw up a scheme for the proposed experiments, which, it was recognized, must continue for many years. The land generously placed at the disposal of the Society was known as Crawley Mill Farm. It consisted of 90 acres, of which 67 were arable and 23 grass. To this a specially suitable field (Stackyard Field) was added in the parish of Woburn, which became the main experimental field of the Station. By the autumn of 1876 the experiments started. The venture had the cordial interest of Lawes and Gilbert of Rothamsted, and it was directed by Dr. Voelcker under the supervision of a special committee of the Royal Agricultural Society. From the start it was decided not to confine the experiments to finding the residual values of foodstuffs, but to duplicate, on the very different soil at Woburn, many of the tests already made at Rothamsted. The central problem, however, was the valuation of unexhausted manures, to which no less than 16 acres of the main experimental field were devoted.

The site chosen for the first experiments has special interests. It lies chiefly on the lower greensand, and so consists of a light sandy loam. This is important when results are compared with those obtained at Rothamsted and other centres. This soil was carefully studied many years later by E. M. Crowther (2), who described it

as follows: "The mechanical composition is uniform down to 24 inches, below which there is a sudden fall in the silt content and an increase in the coarse sand and stones. . . . The rapid decrease in the organic matter with depth and the poverty of the deep soil were shown by analysis." The chief chemical point to note is the small amount of calcium in any form, and the slight acidity, though this is rarely enough to prevent the healthy growth of most ordinary farm crops. The experimental field was in good heart, and drainage was excellent.

Though this type of soil is typical of most of the Station, there is some heavy silt based on Oxford clay, but this was, and still is, little used for experiments.

The experiments during the first twenty years studied three questions (3). The first, already referred to, was the relative manurial value of animal feeding with rich and poor foodstuffs. The second to repeat, with modifications, experiments with continuous wheat and barley given various fertilizers and manures of the type originally done by Lawes and Gilbert at Rothamsted. The third, introduced a little later, concerned so-called green manuring, that is to say the attempt to use one crop to manure the ground for a more important one to follow. Except for animal-feeding experiments, these represented the staple work at Woburn till 1898.

In 1897 two important things happened. First, the Royal Agricultural Society received a bequest from Mr. E. H. Hills of £10,000 to study the manurial effect of the "tertiary constituents of plant ash" better known in later years as trace elements. It was decided to do the desired experiments at Woburn, so a small laboratory and a well-equipped pot-culture station were built and opened in January 1898, when I took charge as resident chemical assistant. Up to that date all the necessary chemical and other analytical work had been done at the laboratory of the Society in London; the establishment of the laboratory made possible a much closer scientific control of the work done than previously.

The establishment of the laboratory, and the development of pot culture on a considerable scale, opened a new phase, which permitted the terms of the Hills bequest to be fulfilled and to study specific problems as they arose in the course of the work at Woburn. With the appearance of new and interesting phenomena in the original field experiments, as well as in others afterwards established, there was a period of great activity and 1898–1914 was perhaps the busiest period in the history of the Station till 1928. I left in March 1900 to go to India; my successor as resident chemist, Mr. H. M. Freear, obtained results of great interest, some of which were published in the *Journal of the Royal Agricultural Society*, but others even now remain in manuscript. Of these I may mention a detailed study of the development and meaning of the acidity acquired in soil from the application of ammonium salts, the development of clover sickness from the repeated growing of clover on the same land, the relative effect of magnesium and calcium salts on the growth of crops, the work with trace elements and that with the field experiments originally started in 1876–77. The outbreak of war and the death of Mr. Freear in 1914 inevitably decreased the

work and new developments were few in the next years. Also in 1912 the Duke of Bedford, who had generously paid all the costs of the experiments at Woburn, decided to withdraw this financial support, although he allowed the farm and buildings to remain with the Royal Agricultural Society for experimental work. From 1912, the cost of the Station was borne by the Society until 1921, when it withdrew from the control and management. Dr. J. A. Voelcker, the consulting chemist to the Society, then maintained the Station at his expense, except for a small subsidy from the Ministry of Agriculture, given on the understanding that the work would be supervised from Rothamsted. Since 1921 the annual reports of the work at Woburn have been issued as part of the Rothamsted reports.

The general results of the work of the Station, excluding the results of pot experiments, to the year 1926 were published by Russell and Voelcker in 1936 under the title *Fifty Years of Field Experiments at the Woburn Experimental Station.* This book is now difficult to get, as the whole stock at the publishers was destroyed by enemy action in the Second World War, yet the fact that it still exists, with a statistical portion by W. G. Cochran, makes it unnecessary for me to describe the work of the Station in detail up to that time. But another period of great activity started in 1928, and I shall summarize part of what has been done since then.

Before doing so, however, I wish to acknowledge the great debt owed to the late Dr. J. A. Voelcker, who from the death of his father in 1884 was Director of the Station till 1936, first under the Royal Agricultural Society and then under Rothamsted. His zeal and his interest in the experimental work never flagged; to the last year of his life he visited and inspected the work month by month, and there is no doubt that but for him the Station would have ceased to exist.

After I retired from my post in India, Sir John Russell invited me to return to Woburn and take charge of the experimental work there. I did this in 1928, when the farm was managed from Rothamsted, but in 1936 I also became responsible for running the whole farm, an arrangement which continued till 1946. Since then Mr. J. R. Moffatt has directed all the farming operations, both of the field experiments and the non-experimental crops. For the next 10 years, I was concerned only with the experimental work in the field and the laboratory, and at the end of 1956, when I officially retired, Mr. C. A. Thorold took over these duties.

Since 1926 the major changes and developments in the field experiments have been the adoption of the modern experimental designs developed by R. A. Fisher and his successors at Rothamsted. The new designs were applied to many problems that widened the interests of the Station. Among new experiments have been the study of what happens under a well-planned rotation of field crops, well manured but without adding extra organic manures for a long period; the first direct tests in this country of the effects of so-called ley farming on the fertility of the land; the relative value of coarse organic manures, including sewage sludge and several composts, in increasing the productivity of poor agricultural land; and the suitability of a number of new or lesser-known crops, such as soybeans,

maize grown for grain and several fodder crops, for slightly acid land. Irrigation trials have included tests on different amounts and times of watering on potatoes, sugar beet, barley, wheat and beans, as well as on both a mixed grass and clover sward and one composed of grass only.

In the laboratory and pot-culture station the most important questions studied have been: (*a*) the comparative value of green manuring by various types of crops and mineral fertilizers as sources of nitrogen; (*b*) the effect of soil acidity on the composition of barley and on crop failures; (*c*) the reasons for the failure of clover when grown frequently on the same land, and (*d*) the competition between weeds and grain crops.

Chief Work of the Station

This outline history of what, except for Rothamsted, is the oldest agricultural experimental station in Britain, now requires an account of the more important results obtained during the eighty years of its existence. For many of the experiments it will suffice to do little more than refer to the published records of what was done and the conclusions reached. At first nearly all these were published in the *Journal of the Royal Agricultural Society*, and were summarized in 1936 in the book *Fifty Years of Field Experiments*, by Russell and Voelcker. Since then most of the work, apart from the sketchy accounts in the *Rothamsted Annual Reports*, has been issued in a series of papers, mostly in the *Journal of Agricultural Science*. Some of the conclusions will now be summarized and references made to the sources where further details can be seen. Some notes will also be given of work which has not so far been published.

Valuation of the unexhausted value of manures

What are the conclusions from the Woburn experiments on the primary problem for which the station was established, namely the relationship between the chemical composition of feeds given to animals and the value of the manure they produce? These experiments, continued with various modifications from 1876 to 1932, always gave similar results. The tests made consisted of crops grown in a four-course rotation, usually either the Norfolk four-course rotation or some modification of it, in which the roots were fed off to sheep, and in the earlier forms of the experiment the wheat crop was also manured. Contrasting plots manured with dung made with high-nitrogen oil-cake (decorticated cotton-cake was used at first) and similar plots with dung made with low-nitrogen foods like maize meal or grain of any sort, should show for each following year whether the high-nitrogen foods gave a more powerful or more lasting manure.

After fifty years Voelcker summarised the results as follows:

> " A review of the results forces one to the conclusion that the experiments have entirely failed to show any marked superiority of cake feeding over corn feeding on the soil. The most that can be said is that the barley immediately following the sheep-folding showed a small advantage for cake as against corn. But no subsequent crops benefited. The highest gain in barley from cake feeding did not exceed 6 bushels per acre and even when there was as much difference as the equivalent of

2 cwt of nitrate of soda between the cake and corn feeding, the crop difference only came to 1 to 2 bushels per acre of barley.

"No explanation can as yet be given for the failure to recover the added fertilizer constituents. It was at first supposed that the feeding of the land was too liberal and the crops too large to indicate any difference between the higher and the lower manuring. But when the feeding was reduced and only given once in the rotation the differences were not more strongly marked, not even when growing barley without manure for a number of years. The substitution of green crops like mustard for clover in the rotation did not help though the wheat crop following clover was larger than that following mustard. All said and done, there remains the fact that much more nitrogen has gone into the land by the use of cake than by that of corn and yet for some reason or other it has not become available for use." (4)

This quotation summarized the position when the work had continued for fifty years. The question has since been approached by Mann and Barnes by means of pot experiments; it seems now clear that when organic manures containing more than so much nitrogen (usually about 2 per cent nitrogen of the dry matter) are applied to land the nitrogen is soon lost either as elementary nitrogen (5) or possibly as nitrous oxide (6), and that within a few months the land is in the same condition as if a less-rich material had been added. In fact, it seems likely that unless the nitrogen in a rich manure is captured by growing plants shortly after it is mixed with the soil it is lost for ever (7). It seems likely that this is what happened in the long-continued experiments noted above and what made the original tables of Lawes quite wrong in the manurial value they gave to the richer forms of organic manure.

Continuous growing of wheat and barley

The results obtained for the first 50 years of growing wheat and barley continuously on the light, slightly acid and lime-free soil at Woburn were thoroughly analysed by Russell (8). The chief effect sought in the original plan of the experiments was that of nitrogen, and phosphatic and potash manures were always applied together. The nitrogen was, however, added in three different forms, and in four different quantities, as nitrate of soda, as sulphate of ammonia and as farmyard manure. The first two supplied nitrogen at the rate of 41 and 82 lb nitrogen/acre each year, and the farmyard manure at rates not exactly determined, but probably about 53 and 105 lb./acre.

During the first 15 years the yields were high, and those of winter wheat on this light land, usually not considered as suitable for this crop, were almost as great as of barley. The three manures differed in effectiveness among themselves. Sulphate of ammonia was somewhat inferior to nitrate of soda and farmyard manure considerably inferior, yet each of them acted similarly on both crops. The different manuring made very little difference to the proportion of grain to total produce.

After 15 years something started to go wrong with the plots given ammonium salts. The crops failed in patched and resowing did not give a crop. This was attributed to exhaustion of calcium, and in 1897, after 20 years of cropping, lime was added to one-half of each of the plots. The yield recovered to that in the early years of the experiments. This was 1891, a time when the question of

soil acidity and its influence on yield was first considered and experiments by Wheeler (9) in Rhode Island, U.S.A., showed how injurious acidity could be. I remember going to Stackyard Field in 1898 with a book of litmus papers and finding that the plots treated with ammonium salts had soil which reddened litmus paper. The further addition of ammonium salts reproduced the trouble, and within a few years the yields had again become very small; finally, the crop failed completely, particularly the barley, and the plots carried simply a mass of spurrey (*Spergula*). The need to apply lime in British agriculture was greatly emphasized by these results, for though medieval agriculture made the marling of land very important, the reason was hardly understood. Nowadays, the importance of dressings of lime on many, if not on most, of the soils of Britain is fully realized.

It has long been accepted that cereals should not be grown frequently on the same land, particularly on light land. The results of the Woburn and Rothamsted experiments allowed Russell (8 & 10) to discuss the subject. He concluded that they can be grown for several years provided that weeds and serious pests and diseases can be controlled. This, though, is difficult, and yields at Woburn have undoubtedly been greatly affected by weeds, and by take-all (*Ophiobolus graminis*), which has been very serious. Whether acidity, weeds and diseases are the only causes of declining yields, I doubt.

De Candolle suggested a century ago that plants excrete from their roots something injurious to their own species but not to plants of a different kind. This certainly seems to happen with some crops, notably with clover (see below), and recent experience with both wheat and barley on the light land at Woburn makes me favour this as a possible explanation with these two crops. It is of interest that only one treatment has maintained yields reasonably well, and that is farmyard manure applied each year at the rate of 8 tons/acre.

Green manuring experiments

The practice of growing one crop to prepare the ground for a second and more important one is common, and has in many places entered into general use. It has, though, often failed to increase the yield of the succeeding crop or to increase the fertility of the soil.

A striking example of green manuring failing to give benefit occurred in the long-continued experiments at Woburn conducted by Voelcker, in which vetches and mustard were used to prepare the land for winter wheat. Whether the green crop was ploughed into the land or fed to sheep, and whether or not phosphates and potash were given, the following crop of wheat was small and became poorer and poorer as the experiment was continued. Further, wheat after the vetches, particularly early in the experiments, consistently yielded less than after mustard, even though the nitrogen buried with the leguminous plants was double or treble that with mustard. The history of these experiments up to the year 1932 was considered by Crowther and Mann in 1935 (11), who concluded that a green manure crop must be large to be effective, that when the green manure has a low carbon–nitrogen ratio (like vetches) its

manurial value is short-lived and soon lost, and that its value will show only in the presence of a crop that uses the nitrogen as the green manure rots and it becomes available.

Further work with field crops and in pot cultures since 1933 confirmed the conclusions of Crowther and Mann and showed that beneficial results come from green manures containing a high percentage of nitrogen only when the following crop is taken very soon after the green manure is buried. The crop-producing power of nitrogenous manures depends, in the main, on two factors, namely: (1) the length of time they have been in the soil before the next crop is sown, and (2) their content of nitrogen. With materials containing much nitrogen, the maximum benefit is obtained after they are buried for only a short time, and the benefit decreases with increasing time before a crop is present, even when there is no loss by drainage. The time after ploughing in that gives the maximum benefit to the succeeding crop increases as the percentage of nitrogen in the green manure decreases. All manures containing much nitrogen, whether organic or inorganic, show this decreased effectiveness as the interval between their application and the sowing of the crop increases. However, when the nitrogen in plant or animal residues is less than about 1·8 per cent of the dry matter, their immediate use as manures decreases the crop-producing power of soil. From this amount to between 4 and 6 per cent of nitrogen the crop-producing capacity increases and does so more rapidly than the actual nitrogen increase. When the percentage of nitrogen goes above this, the crop yield does not increase, though the recovery of nitrogen may be greater. Different plant materials with the same percentage of nitrogen did not behave exactly alike, though their behaviour was similar. There is no evidence that any of the materials used, including farmyard manure, greatly increased the amount of *residual* nitrogen in the soil. After the first crop was taken, whether the green manures contained much or little nitrogen, the addition had no further effect.

The importance of organic manures in land fertility

Whether organic manures are needed to maintain the fertility of land is often discussed and an experiment was started in 1930 in which crops in a six-course rotation were supplied with inorganic fertilizers but no organic manures. The experiment was originally designed to test the effect of weather on crops, but its chief interest changed to the function of organic manures and the extent to which yields can be maintained without them. The results after 25 years are being examined by others, but I can say that there is as yet little sign that the land is deteriorating. Certainly the yields of four of the six crops grown, namely barley, rye, potatoes, and sugar beet, are being maintained. Conclusions are less definite with winter wheat and clover, because the wheat has been consistently poor, for some unknown reason, and the clover is so seriously attacked by clover rot (*Sclerotinia trifolium*) each year that no valid conclusions can be drawn about soil fertility.

Another experiment on the importance of organic manures in maintaining the fertility of light soil has given different results. An area that had become very poor, and from which only meagre

crops were obtained for some years, was put down in 1942 to an experiment with market-garden crops. Various coarse organic manures were annually applied in large quantities to see whether their use increased the fertility of the land. The experiment, now 17 years old, was designed to answer the following questions: (1) whether the presence of organic matter is essential to maintain the productivity of such a soil; (2) whether different organic manures are of equal value in increasing and maintaining fertility; (3) whether fertility increases immediately or steadily over a long period of applying organic manures; (4) whether the organic manure has a specific effect not determined by its content of plant nutrients.

Most of these questions have been answered in part, and some answers are unequivocal. The answers vary with different crops; of the four grown, namely globe beet, green peas (seeded on the plots), cabbages and transplanted leeks, cabbages and peas do not respond specifically to the organic manures, but globe beet and leeks do. With cabbages the same yields were obtained by extra mineral fertilizers as with organic manures, and peas were little affected by manuring. With globe beet and leeks, however, organic manures gave large increases in yield that were unobtainable with inorganic fertilizers. Different organic manures are difficult to compare accurately, but on the basis of the amount of organic matter added, farmyard manure was similar to a compost made with straw and weeds and activated with dung, and much superior to sewage sludge and a compost activated with sewage sludge. Fertility seems only slightly increased by annually repeated applications of the manures, and the increase from manuring, except with globe beet, is now almost the same as it was in the first 3 years. Doubling the dose of manure does not double the response, but increases it by about 60 per cent. The question of a value in the organic manures other than their recognized content of nutrients remains unanswered, but the experiment is being continued, and a complete answer may be obtained. In the meantime Mann and Barnes (13) studied the permanence of the organic matter in the soil. The soils after each treatment were analysed after 9 years, when: (1) Different materials were found to divide into two classes, different in activity. Farmyard manure is much more active than sewage sludge or either of two forms of compost, which do not differ much from each other, though the least active is the compost made with sewage sludge. (2) A top dressing of sulphate of ammonia decreases the rate at which the last three disappear from the soil. (3) Doubling the amount of manure added led to their more rapid disappearance.

Ley farming

I now turn to one of the most interesting field experiments of the last few years, namely that dealing with the value of ley farming. This was started in 1937, and a paper by Boyd and Mann (14) gives the full results. The leys used were a 3-year grazed area and a 3-year crop of lucerne cut for hay; the arable cropping with which to compare the results consisted of potatoes, a winter cereal crop and either a 1-year ley or another tillage crop. The relative effect of these crop sequences was measured by test crops of potatoes

followed by barley, uniformly treated except that 15 tons of farmyard manure were applied for the potato crop on half of each plot. Without farmyard manure, potatoes after the grazed ley yielded consistently more than after the three tillage crops by about 3 tons/acre (23 per cent); after lucerne it was about 2 tons/acre more than after the tillage crops, and after the 1-year ley it was less than 1 ton more. With farmyard manure the benefit from leys was less, about 2 tons/acre for both lucerne and the grazed ley. The average effect of the farmyard manure (at 15 tons/acre) was 2·8 tons of potatoes, except after the grazed ley where it was only 1·6 tons/acre. Effects of the previous cropping on the yield of barley were small in the early years of the experiment, but later the yield after leys and lucerne exceeded that after tillage crops by about 15 per cent.

Irrigation experiments

In 1951 a new and important development was the start of experiments to measure the value of irrigating field crops and grass leys at Woburn, and this has since continued with some modifications. I shall not discuss the results in detail, as the work continues and will be described by H. L. Penman, under whose general direction it is done. However, the results with different crops can be stated; in spite of the fact that 6 years out of 8 have had dry periods in March and April, irrigation has had little effect on cereals; its value has varied from year to year with sugar beet and grass, but in 6 out of 8 years it has been highly profitable with potatoes, whether early or main crop. One point of peculiar interest is that, in two seasons when a mixed grass and clover sward was grown, the proportion of clover in the cut herbage was considerably greater on the irrigated plots. T. W. Barnes uses the experiment to study the uptake of nitrogen by grass and how it is affected by watering.

New and unusual crops

In recent years several unusual crops have been grown to see how far they have any use on a slightly acid light soil such as that at Woburn. Almost all available varieties of **soybeans** have been tried, but none proved promising enough to suggest their cultivation on a large scale. On the other hand, **maize grown for grain** gave good results when the hybrid varieties now early enough for the English climate were used. Using the best of these varieties, developed from American types in Holland, we have got an average yield of nearly 35 cwt./acre of dry grain in good summers, falling to about 15 cwt./acre in cold, wet years. The crop suits smallholders, as the amount of seed required is small, it can be grown in almost any odd corner and the maize ears can be used for chickens or even for pigs without threshing. Another crop which seems to have possibilities is the **Jerusalem artichoke** in the form of a specially luxuriant variety developed in Germany. This has given an average yield of leafy tops of over 3 tons of dry matter/acre, which are readily eaten by pigs and make good silage, and over 12 tons of tubers, which from all tests elsewhere are as good as potatoes for pig feeding. It is clear, however, that this crop is only suitable where the soil is light and well drained.

Special interest attaches to efforts to extend the range of fodder crops suited to semi-acid land, and several of these have possibilities in this country. One is the **sweet lupin**, which has given us good results in many years. Though the fodder produced is not at first relished, animals soon get used to it and then eat it readily. In our tests we have been able to get an average of 12·5 tons of green fodder/acre containing just under 2 tons/acre of dry matter. This crop, which is now used fairly extensively in New Zealand, seems to have considerable possibilities on the more acid lands, especially in the eastern counties of England. **Serradella** is similarly suitable to acid soils, and we have grown it for a number of years as a fodder crop for use in September when grass is beginning to fail. The seed used at Woburn was originally obtained from the U.S.A., but it has been maintained with home-grown seed obtained in the drier years. The crop contrasts with lupins in that it is eaten greedily by all classes of stock. In wet years, such as 1954 and 1956, it gave large yields of green stuff in September; in 1956 30 tons of green forage were grown containing 11 per cent dry matter. No seed was obtained in this wet year, but in 1955 it was abundant and of good quality. Of other successful fodder crops for acid soils, I might mention **Birdsfoot Trefoil**, which has grown well, though slowly, but which gave in October 1956 4·7 tons of green stuff/acre, containing 16·6 per cent of dry matter. The seed was obtained from the U.S.A., where much work has been done to improve the crop, and the improved types seem to have prospects as fodder crops in Britain.

Studies of acid soils and the barley crops grown on them

Barley grows normally on Woburn soil until the acidity falls below pH 5·4. This is so whether normality is judged by the vegetative growth, by the character of the earing, by the composition of the plants during growth or by that of the straw and grain at harvest. When acidity reaches a pH value between 5·4 and 4·7 abnormalities occur. The plants are dwarfed, and the grain-bearing capacity is greatly affected. The number of leaves, shoots and heads per plant are not much decreased, but the plants are dwarfed and sickly, with the leaves yellow at the tips and purple in the veins. These effects all increase with increasing acidity beyond what may be called the " critical point ". In the more acid soils the amount of oxide of iron and alumina in plants may be three times the normal percentage, but the total ash content is decreased, for silica, calcium and phosphorus are all decreased; so also is the percentage of nitrogen (15).

When an acid soil is treated with calcium carbonate the pH value rises to a point at which good growth of barley is again possible, but adding more calcium carbonate does not further increase the yield. Extreme acidity of the soil, even when equivalent to a pH value of 3·5, is no bar to nitrification. The amount of soda removed by drainage from these acid soils is little affected by the pH value of the soil. On the other hand, the leaching of potash is much greater than has been generally thought. The more acid the soil, the higher the proportion of magnesium to calcium in the drainage water. The amount of alumina in the drainage waters remains almost constant

till the pH value is below 4·6, but at 4·1 it increases to nearly four times the previous amount, though even then it is very small (16).

Competition of weeds with arable crops

A unique series of studies has been made by Mann and Barnes on the competition of barley with various plants, weeds such as spurrey (*Spergula arvensis*), mayweed (*Metricaria inodora*), *Holcus mollis*, *Agrostis gigantea*, chickweed (*Stellaria media*) and clover. No evidence was found except perhaps with *Holcus mollis* that any plant acted specifically on the barley. The roots usually intertwine with no sign of mutual attraction or repulsion. With abundant nitrogenous manure, clover behaves like the other plants (17).

Soil sickness from frequent growing of clover

In 1860 Lawes and Gilbert drew attention to the failure of red clover when frequently grown on the same land. In the early days of the Woburn Experimental Station this problem received attention, and its study was taken up seriously by Mann about 20 years ago. A first result was published in 1938 (18), but the work has continued ever since, and a further note was published in 1950 (19). The general conclusions that have been reached can be summarized as follows: though the experimental results do not conclusively establish the cause of the failure, they do indicate clearly the direction in which a solution to the problem of this and similar soil sicknesses will be found. The evidence is strong that the trouble is not pathogenic but is induced directly by the continued or frequent growth of clover on the same soil. The soil is not rendered unsuitable for gramineous plants like barley or ryegrass, but radishes, lettuce and spinach beet are affected almost to the same extent as clover. The advent of the sickness is slightly accelerated by increasing the temperature at which clover is grown, but is still more accelerated by growing many plants in a little soil.

Three methods have been found by which soil seriously affected by this clover sickness can be, at least partially, restored to a healthy condition. The first is by heating the soil, preferably moist, to 70° C. for some hours. The second is by treating the soil with a heavy dressing of farmyard manure or of a compost activated with dung. This result is not a matter of increasing plant nutrients, as it cannot be achieved by even large dressings of mineral fertilizers. A third, less-effective method, is to add calcium carbonate and decrease acidity.

All attempts to leach out any causative substance from the soil have failed. It is not easily oxidized. Treatment with toluene followed by the removal of the antiseptic agent has no effect, but treatment with formaldehyde gave some improvement. I suggest no pathogenic organism is concerned but that the cause is an organic product of the growing clover which is heat-sensitive, insoluble in water, not affected by antiseptics, tending to be more active in slightly acid soils and whose activity is somewhat reduced by certain colloid organic materials like farmyard manure or charcoal, but not by all.

Conclusion

I have dealt with the principal work done at the Woburn Experimental Station during its 80 years of existence. Beyond this, many studies have been made, both in the field and in the laboratory by members of the Rothamsted staff, and others which have had a temporary, though often important, connotation. The record of these can be found in the annual reports of the Station issued up to 1920 in the *Journal of the Royal Agricultural Society*, and, since then, in the annual reports of Rothamsted. As for the former class of experiments, they have been published in various journals under the names of those responsible.

The future is likely to show the continuing importance of the work, and I hope to see a gradually increasing amount of scientific activity at Woburn, which will lead, in ever-greater measure, to results important to the agricultural industry in Britain.

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PUBLICATIONS

Physics Department

1.1. CASHEN, G. H. (1959). Electric charges of kaolin. *Trans. Faraday Soc.* **55**, 477–486.

Two methods of measuring the negative charge of kaolin, using cetyl trimethyl ammonium bromide, have shown that kaolin possesses a permanent isomorphous replacement charge. The presence of positive edge charges in acid conditions has been confirmed. It is suggested that the release of aluminium from acid-washed clays is a consequence of the formation of these edge charges, the crystals becoming unstable as electrolyte is washed away and the potential difference between the planar and edge faces rises.

1.2. DETTMANN, Margaret G. (1958). Water uptake by pure clays and soil crumbs. *J. Soil Sci.* **9**, 306–315.

Wetting experiments on pure clays are described that lead to the conclusions that entrapped air is neither a necessary nor an important factor in slaking of dry soils, and that slaking is always associated with rapid intercrystalline swelling of the clay. If swelling is suppressed, or takes place slowly—as from a vapour phase—slaking does not occur, and it is suggested that slow swelling gives time for readjustment of the internal geometry of the clay, so producing some dislocation but no disruption. In *N*-NaCl a Na-montmorillonite swells to about twice its dry thickness, and in an atmosphere of 98 per cent relative humidity it gains about one-third of its weight. Both these figures are in agreement with the usual estimate of surface area of 800 sq. m./g. Under the same conditions a Na-illite (from Willalooka) swells by about a third of its dry thickness, and gains about a quarter of its dry weight.

Studies on rates of uptake of water vapour indicate that montmorillonite has taken up less than a quarter of its equilibrium water content at 98 per cent relative humidity within 10 minutes, whereas illite has taken up one-third of its water in the same time, the clays being stable against subsequent flooding.

In the field it is probable that water vapour diffuses ahead of a liquid wetting front, and the protective effect of the resultant slower pre-swelling of the clay prevents the slaking action of rain from affecting more than a thin surface layer of soil.

1.3. DETTMANN, MARGARET G. & EMERSON, W. W. (1959). A modified permeability test for measuring the cohesion of soil crumbs. *J. Soil Sci.* **10**.

The technique previously described (Emerson (1955) *J. Soil Sci.* **6**, 160) has been improved. A 1-cm. thickness of soil crumbs of standard size (1–2 mm. diameter) is supported on a 1-cm. layer of glass spheres (0·5–1 mm. diameter), and the permeability measured by percolation of 0·05*N*-NaCl—the so-called " initial " test. Then 3 litres of the same solution are percolated in 24 hours, after which the permeability measurement is repeated—the " final " test. The ratio, K_2/K_1, of final and inital permeabilities of the crumbs is regarded as a measure of soil cohesion.

The technique has been applied to a wide range of soils, on some of which other structural tests had already been made. The results, in four tables, show: (*a*) a continuous arable system produces very bad structure; (*b*) a short-term ley produces an improvement—as does wheat—and some of the improvement is detectable after a subsequent year in arable cultivation; (*c*) attainment of maximum stability is very slow, for apparently 100 years in grass is not long enough; (*d*) farmyard manure residues produced an increase in crumb stability on a clay soil, but no detectable increase on a sand; (*e*) a ley, and lucerne too, produces a greater increase than root crops.

Limitations of the test are: (*a*) it should not be used unless the soil acidity is approximately the same for all samples. Very acid clay (pH 4–5), known to possess a very poor structure, gives a value of K_2/K_1 close to unity. (*b*) It may not be safe to compare soils of differing clay content. A poorly structured sandy loam (12 per cent clay) gives a much higher value of K_2/K_1 than a clay loam (31 per cent clay) that field experience would assess as having the better structure.

1.4. Monteith, J. L. & Owen, P. C. (1958). A thermocouple method for measuring relative humidity in the range 95–100 per cent. *J. sci. Instrum.* **35**, 443–446.

At high relative humidities a current of 30 mA through a 38 S.W.G. chromel-*p*/constantan thermocouple produces sufficient Peltier cooling to form a film of water on the junction which may then be used as the wet-bulb of a psychometer. The wet-bulb depression can be read to 0·001° C. and in the range 97–100 per cent changes of 0·01 per cent relative humidity can be detected.

After calibration over sodium chloride solutions the psychrometer has been used to determine the water content/free energy curves of two soils, and good agreement has been obtained with previous determinations by other methods.

1.5. Penman, H. L. (1959). Notes on the water balance of the Sperbelgraben and Rappengraben. *Mitt. schweiz. Anst. forstlich. Versuchsw.* **35** part 1 (Festschr. 70. Geburtstag, Hans Burger), 99–109.

Twenty-five years' data for the two catchments are available as rainfall (*N*) and runoff (*A*). For the forested Sperbelgraben the values of *N*–*A* are greater than those for the mainly grassland Rappengraben, both in annual totals and in mean monthly values. Making the assumption that the annual water balance for each catchment is not greatly different from one year to the next, the annual data are statistically treated to give a correction factor for *A* for each catchment. Applying the correction brings the annual water balances into near agreement, closer than the variation from year to year in either; brings the mean monthly balances to almost exact agreement, and introduces a surprising degree of identity in the short period (2 or 3 days) responses of the catchments to rain.

The monthly and annual mean values of *N*–*A* are compared with empirical and theoretical estimates based on weather data (Turc, Thornthwaite and Penman). All three of these estimates are in broad agreement as giving the expected mean value of *N*–*A* as near 500–550 mm./annum, with the forested area losing perhaps 10–15 per cent more than the grassland; the corrected value of the means is about 625 mm./annum for both; and the observed values, uncorrected, are 860 and 695 mm. respectively.

Chemistry Department

General Papers

2.1. Benzian, B. (1957). Nutrition problems in forest nurseries. Copper deficiency in poplar. Summary report for 1956. *Rep. For. Res. For. Comm. for 1956/57*, p. 98.

2.2. Cooke, G. W. (1958). Soils and fertilizers. *J.R. agric. Soc.* **119**, 105–121.

2.3. Cooke, G. W. (1958). Recent advances in the efficient use of fertilizers. *J. Inst. Corn. Merch.* **6**, 196–204.

2.4. Mattingly, G. E. G. (1957). Crops. *Rep. Progr. appl. Chem.* **42**, 566–572.

Research Papers

2.5. Arnold, P. W. (1958). Potassium uptake by cation-exchange resins from soils and minerals. *Nature, Lond.* **182**, 1594–1595.

Some results of the interaction of both soils and micaceous minerals with sodium-, calcium-, and hydrogen-saturated cation-exchange resins are given. The extent of the extraction of potassium from the minerals by hydrogen-resin is interesting; whereas dioctahedral minerals release little of their non-exchangeable potassium to hydrogen-resin, the trioctahedral minerals suffer considerable loss of potassium. Hydrogen-resin data may prove useful in assessing the long-term ability of soils to supply potassium to crops.

2.6. Bremner, J. M. (1958). Amino sugars in soil. *J. Sci. Fd Agric.* **9**, 528–532.

The identity of the amino sugars in various soils was studied by several chromatographic techniques. Glucosamine and galactosamine were detected in every soil examined, both amino sugars being isolated as their hydrochlorides from one soil and characterized by X-ray, ultimate and paper chromatographic analysis. Observations on the decomposition of glucosamine in alkaline solution are discussed.

2.7. Cooke, G. W. (1958). The nation's plant food larder. *J. Sci. Fd Agric.* **9**, 761–772.

The crops and grass grown in the United Kingdom in any one year need about 1 million tons each of N and K_2O and about one-third as much P_2O_5. Sales of cash crops, milk and stock, and the losses involved in feeding crops and grass on farms may result in about one-third of these quantities of plant foods being lost to agriculture. Fertilizers and imported feeding-stuffs provide sufficient plant foods to balance approximately the total losses of nitrogen and potassium, and they supply much more phosphorus than is lost. These sources of plant food currently provide only half of the nitrogen and less than half of the potassium that is needed for a year's cropping. In contrast, fertilizers alone supply more phosphorus in any one year than is taken up by the crops and grass grown.

The history of the use of fertilizers in the United Kingdom is discussed. About 7 million tons of N, 17 million tons of P_2O_5 and 5 million tons of K_2O have been applied to the soils of the United Kingdom through the use of fertilizers in the last 120 years. In the 18 years from 1940 to 1957 fertilizers supplied as much nitrogen, twice as much potassium and half as much phosphorus as was applied in the previous 100 years. The surface layers of the cultivated soils of the United Kingdom contain plant foods equivalent to about 200 years' supply of nitrogen, 100 years' supply of phosphorus and 1,000 years' supply of potassium at current rates of fertilizer use. The amounts of phosphorus applied to United Kingdom soils have exceeded losses of this nutrient for at least 80 years, but only in recent years have the potassium fertilizers used been sufficient to avoid depleting soil potassium reserves. The size and nature of the reserves of soil phosphorus which have accumulated in British soils as a result of manuring tend to be more important for the nutrition of arable crops than the supply of " native " soil phosphorus. In contrast, the reserves of potassium built up by residues from purchased fertilizers and feeding-stuffs are relatively small, and the capacity of soil minerals to supply potassium to crops is very important.

Future prospects for increases in the use of fertilizers are examined. Most arable root crops grown for sale are now receiving about as much fertilizer as can be justified, but more nitrogen is needed to grow full crops of cereals, and practically all crops grown for animal feeding are, on average, undermanured. Any major increase in the total amount of fertilizer used is likely to be achieved by better manuring of grassland.

2.8. Gasser, J. K. R. (1958). Use of deep-freezing in the preservation and preparation of fresh soil samples. *Nature, Lond.* **181**, 1334–1335.

Storage at −10° maintained the ammonium and nitrate contents of soils unchanged for periods up to 32 days. An increase in the mineral nitrogen

content of soil occurred both during storage at 2° continuously, or at −10° and 2° alternately.

Prolonged deep-freezing or freezing and thawing up to 16 days did not affect the amount of mineral nitrogen formed on subsequent incubation of the fresh soil; air-drying after prolonged storage by either method, followed by re-wetting and incubation, resulted in less mineral nitrogen being formed during incubation than occurred when the unstored soil was used.

The physical condition of heavy soils was much improved by deep-freezing, and the resulting crumb structure facilitated sub-sampling, and also crushing and sieving after air-drying.

2.9. Heintze, S. G. (1957). Studies on soil manganese. *J. Soil Sci.* **8**, 287–300.

While results of extractions, performed in the presence of reducing agents, of mineral soils low in organic-matter content suggested that manganese higher oxides approaching the manganese dioxide type are present or formed by oxidation of added manganese, results obtained with other extractants lend support to the suggestion by Dion and Mann that hydrated manganic oxides may occur in such soils.

From the distribution of manganese in various extracts of alkaline organic soils with or without added manganese materials, it was concluded that no difficultly reducible higher oxides of manganese are present or formed. Some evidence was presented for the view that manganese of a higher valency form may remain in combination with the organic matter or may be retained in this manner after oxidation of added manganese.

Divalent manganese present as a complex of the organic matter of alkaline organic soils could be estimated by extraction with a monocalcium disodium versenate solution. It constituted 10–20 per cent of the total manganese content. Manganese added to such soils and not present as readily soluble manganese was recovered by this extractant shortly after application; manganese did not, however, remain in this form after some weeks' contact with soils.

The organic matter of various soluble organic-matter fractions migrated anionically over a wide pH range; that of lignin solutions remained at the iso-electric point. Manganese already present in soluble organic-matter fractions migrated anionically in contrast to manganese added and retained by such fractions that moved predominantly as a cation.

The oxidizable carbon or total nitrogen content of soluble organic-matter fractions was not closely related to the amounts of manganese retained by such fractions in a form that was non-dialysable against potassium chloride. Some evidence was obtained that different types of complexing groups may be present in water extracts subsequent to extraction by sodium chloride of an alkaline fen and of an acid raw-humus peat.

2.10. Mattingly, G. E. G., & Widdowson, F. V. (1958). Uptake of phosphorus from ^{32}P-labelled superphosphate by field crops. Part II. Comparison of placed and broadcast applications to barley. *Plant & Soil*, **10**, 161–175.

Three field experiments with barley were carried out in successive years at Rothamsted to compare at different stages of growth, the uptake of phosphorus from ^{32}P-labelled superphosphate that was drilled with seed (5 lb. P/acre) or broadcast on the surface (10 lb. P/acre). The yields and total phosphorus uptakes obtained with equal amounts of radioactive and non-radioactive superphosphate were compared in 2 years in the field and in a single greenhouse experiment.

^{32}P-labelled superphosphate slightly reduced yields and total phosphorus uptakes in both field experiments, but the reductions in yield and uptake were seldom significant. In the greenhouse experiment similar yields and phosphorus uptakes were obtained with both radioactive and with non-radioactive superphosphate.

The percentage recovery of phosphate from superphosphate applied in seed drills was greater at all stages of growth in each year than from superphosphate broadcast on the seedbed. Recoveries at harvest in different years varied less from drilled superphosphate (10–15 per cent) than from broadcast superphosphate (5–12 per cent). At the rates of application tested in these

experiments, uptakes of drilled and broadcast superphosphate take place independently throughout the growth of barley.

Drilled and broadcast superphosphate both increased the uptakes of soil phosphate by barley during the early stages of growth. In 1953 when the crop grew rapidly, the extra amounts of soil phosphate taken up 26 and 48 days after sowing were equal to 75 and 100 per cent of the amounts of fertilizer phosphorus taken up from drilled superphosphate and 64 and 23 per cent of the amounts of fertilizer phosphorus taken up from broadcast superphosphate. The increased uptakes of soil phosphorus that resulted from applying superphosphate were smaller in 1954 and 1955. In all years at harvest there was less soil phosphate in crops receiving superphosphate than in unmanured plants.

2.11. Newman, A. C. D. (1958). The separation of fluoride ions from interfering anions and cations by anion exchange chromatography. *Analyt. chim. Acta*, **19**, 471–476.

Fluoride may be separated from phosphate and the anionic metal chelates of ethylenediaminetetraacetic acid (EDTA) by absorption on, and elution from, an anion-exchange column containing a strongly basic resin. This provides a simple and accurate method of removing interfering ions prior to the determination of fluoride by thorium nitrate titration, and is a satisfactory alternative to Willard–Winter distillation. A procedure is described for the determination of fluorine in rock phosphates and other materials soluble in alkaline EDTA solution.

2.12. Newman, A. C. D. (1958). A spectrophotometric investigation of the reaction between fluoride and the complex of sodium quinalizarin sulphonate with aluminium. *Analyt. chim. acta*, **19**, 580–586.

A water-soluble sulphonate of quinalizarin (1 : 2 : 5 : 8-tetrahydroxyanthraquinone) was prepared and its molar extinction from 220–600 mμ recorded. The reaction of this derivative with aluminium was investigated spectrophotometrically and it was found that a complex was formed which exhibited two absorption peaks, one at 265 mμ and one at 495 mμ. The latter absorption peak was used to examine the influence of fluoride ions on the complex, and at pH 3·9 the absorption was markedly decreased by fluoride. A procedure was developed to use this bleaching to determine small quantities of fluoride, and it was applied to the estimation of fluoride in rock phosphates. This application showed, however, that the absorption of the reagent was dependent on pH to an extent which made the method accurate only when very close control of pH ($\pm$0·01) was possible. However, its simplicity enabled the method to be applied to the semi-quantitative analysis of large numbers of solutions per day.

2.13. Shaw, K. (1958). Studies on nitrogen and carbon transformations in soil. Thesis accepted for Ph.D. Degree of London University.

2.14. Stojkovska, A. & Cooke, G. W. (1958). Micro-nutrients in fertilizers. *Chem. & Ind.* 1368.

The amounts of B, Mn, Cu, Zn, Co and Ni in samples of fertilizers and farmyard manure used in Yugoslavia and in England are stated. Most fertilizers make little contribution to the supplies of micro-nutrient in soils. A few fertilizers and also farmyard manure contain appreciable quantities of micro-nutrients, and where these materials are applied in sufficient quantities they may have some value in correcting micro-nutrient deficiencies.

2.15. Warren, R. G. (1958). The residual effects of the manurial and cropping treatments in the Agdell Rotation Experiment. *Rep. Rothamst. exp. Sta. for 1957*, pp. 252–260.

A summary is given of the yields of crops grown in the Agdell experiment. Residues of nitrogen, phosphorus and potassium accumulated in the soils as a result of continuous treatment with fertilizers. The values of these residues for crops were measured after manuring was stopped in 1951, and the results of parallel laboratory investigations are reported.

Pedology Department

3.1. (Beavers, A. H.) & Stephen, I. (1958). Some features of the distribution of plant-opal in Illinois soils. *Soil Sci.* **86**, 1–5.

The presence, characteristics and distribution of opal in some Illinois soils are reported and its origin from the native grasses of the region demonstrated. The grains of opal are particularly abundant in the A-horizons. The value of the plant-opal as an "index mineral" for determining the presence and location of buried A-horizons in palaeosols is indicated.

3.2. Bloomfield, C. (1958). Mobilization of iron in podsol soils by aqueous leaf extracts. *Chem. & Ind.* 259–260.

3.3. Brown, G. & Stephen, I. (1959). A structural study of iddingsite from New South Wales, Australia. *Amer. Miner.* (In the press.)

The iddingsite (an alteration product of olivine) is polycrystalline and consists of goethite and a triphormic layer lattice silicate. In the alteration of olivine to iddingsite the original lattice of close-packed oxygens appears not to have been greatly disturbed and the changes have occurred by the movement of cations within small regions to form microcrystals of the alteration products. The parallel alignment of the components explains why it behaves optically as a single crystal.

3.4. Gower, J. C. & Rayner, J. H. (1958). Crystallographic programmes for a computer. *Brit. J. appl. Phys.* **9**, 446–447.

For summary see below, p. 272, 12.8.

3.5. Stephen, I. (1958). Recent advances in pedology—micromineralogy of soils. *Sci. Progr.* **46**, 317–322.

Soil Microbiology Department

General Papers

4.1. Meiklejohn, Jane (1958). Articles on: Nitrobacteriaceae; Methanomonadaceae; Soil Sulfur Microbial Cycle; Soil Phosphorus Microbial Cycle; Microbial Utilization of Soil Minerals. (In: *McGraw-Hill Encyclopedia of Science and Technology*.) New York: McGraw-Hill.)

4.2. Nutman, P. S. Origin and developmental physiology of root nodules. (In: *Handbuch der Pflanzenphysiologie*, **15**. Berlin: Springer-Verlag.) (In the press.)

4.3. Nutman, P. S. (1959). The physiology of nodule formation. (In: *Nutrition of the Legumes*, ed. E. G. Hallsworth.) London: Butterworth; 87–107.

The following stages in the infection of the root of clover are distinguished: (i) rhizosphere stimulation of bacterial multiplication; (ii) root hair curling; (iii) initiation of infection thread; (iv) infection thread growth; (v) activation of nodule site; (vi) nodule initiation. The influence of root secretion upon these stages in nodulation and the relation of nodulation to rooting habit and to the general physiology of the root are discussed.

4.4. Nutman, P. S. (1958). Sources of incompatibility affecting nitrogen fixation in legume symbiosis. *Symp. Soc. exp. Biol.* **13**. (In the press.)

The known defects in symbiotic nitrogen fixation in *Trifolium* are discussed in terms of the normal development of the root nodule, showing that incompatibility between bacterium and host can arise at different stages in the

establishment of the symbiosis and that these can be distinguished phenotypically and by genetic analysis. The relation between symbiotic and free-nitrogen fixation is also discussed.

Research Papers

4.5. Jackson, R. M. (1958). Some aspects of soil fungistasis. *J. gen. Microbiol.* **19**, 390–401.

A series of fungi with varying degrees of sensitivity to fungistasis was selected as the result of agar disc and buried-slide tests with seventeen fungi and one soil. Six out of seven different soils exhibited a spectrum of inhibition of the test series of fungi similar to that of the first soil tested. The exception was a very acid raw humus soil which only inhibited the acid-sensitive fungus *Acrostalagmus cinnabarinus*. Fertilizer treatments of two series of plots at Rothamsted were found to affect soil fungistasis only through their influence on soil pH. Inhibitory effect decreased with increasing soil acidity, being absent from the most acid plot tested. The results of experiments in which three fungi were pre-incubated before exposure to the influence of soil suggest that spores are most sensitive to soil fungistasis at an early stage in germination.

4.6. Jackson, R. M. (1959). Soil fungistasis and the rhizosphere. (In: *Proc. Soil. Microbiol. Symp.*, Liverpool 1957.) (In the press.)

Experimental details are given of a study of the influence of seedling roots on inhibited fungal spores in soil using the buried-glass-plate and root-observation-cell techniques. In observation cells radish seedlings were more effective than tomato or lettuce in stimulating germination of chlamydospores of three species of *Fusarium* and conidia of *Gliocladium roseum* and *Acrostalagmus cinnabarinus*. After a short period of vegetative development, *G. roseum* and *P. marquandii* started to sporulate vigorously within the root zone of radish. The *Fusaria* were never observed to sporulate in the rhizosphere, but considerable vegetative development frequently occurred. Six monosaccharide sugars tested had a similar effect on soil fungistasis; fungistatic inhibition being partially counteracted by concentrations of 0·01 per cent and completely or nearly so by 1·0 per cent. Disaccharides were less effective and raffinose least effective of the sugars tested. Asparagine, alanine, leucine, Difco Casamino acids and Difco peptone were all found to be ineffective at concentrations up to 0·5 per cent.

4.7. Skinner, F. A. (1959). The decomposition of anionic surface active agents by soil bacteria. *Nature, Lond.* **183**, 548–549.

A species of *Pseudomonas* isolated from soil can utilize primary alkyl sulphates with alkyl radicals containing up to eighteen carbon atoms. The bacterium grows readily in dilute solutions of Teepol 530, a secondary alkyl sulphate, and causes a rapid increase in surface tension. The tendency of stronger Teepol solutions to foam is also suppressed, even though the surface tension rises very little during incubation. Detergent foaming additives of the alkylolamide type are also utilized, but tetrapropylene benzene sulphonate, the active constituent of some commercial detergents, is not attacked. Many soil micro-organisms can tolerate this persistent compound, but none have been found to decompose it.

4.8. Steenson, T. I. & Walker, N. (1958). Adaptive patterns in the bacterial oxidation of 2 : 4-dichloro- and 4-chloro-2-methyl-phenoxyacetic acid. *J. gen. Microbiol.* **18**, 692–697.

Organisms of a strain of *Flavobacterium peregrinum* and an *Achromobacter* strain, capable of decomposing 2 : 4-dichloro-phenoxyacetic acid (2 : 4-D) and 4-chloro-2-methyl phenoxyacetic acid (MCPA) respectively, have been obtained by growing cultures on peptone agar plates containing either 2 : 4-D or MCPA. Glucose did not prevent adaptation. Organisms of the *F. peregrinum* strain were adapted to oxidize 2 : 4-D when grown on peptone agar containing either MCPA or 2-chloro-4-methyl-phenoxyacetic acid; they

did not decompose MCPA. The effects of some related compounds on adaptation to 2 : 4-D by these bacteria were examined. Growth of the *Achromobacter* strain on peptone agar containing either 2 : 4-dichlorophenol or 5-chloro-2-cresol gave organisms which were adapted to oxidize both 2 : 4-D and MCPA as well as the inducing compound.

Botany Department

General Papers

5.1. Humphries, E. C. (1958). Entry of nutrients into the plant and their movement within it. *Proc. Fertil. Soc. no.* 48, 1–36.

5.2. Thurston, J. M. (1958). The maximum recorded survival of weed seeds in soil. *Turf for Sport*, **3**, 3–5.

5.3. Watson, D. J. (1958). Factors limiting production. (In: *The Biological Productivity of Britain*. Ed. W. B. Yapp and D. J. Watson, pp. 25–32.) London: Institute of Biology.

Research Papers

5.4. Humphries, E. C. (1958). The effect of removal of the root-system of barley on the production of ears. *Ann. Bot. Lond. N.S.* **22**, 417–422.

Complete removal of roots of barley plants, grown in water culture, at a stage before the plants have attained their maximum shoot number, results in a significantly greater number of ears at harvest. If the roots are excised when shoot number is beginning to decline the number of ears is decreased. The cause of the phenomenon is not known, but it is suggested that it may be due to a temporary diversion of carbohydrate to the shoots when the roots are excised.

5.5. Humphries, E. C. (1958). Effect of gibberellic acid and kinetin on growth of the primary leaf of dwarf bean (*Phaseolus vulgaris*). *Nature, Lond.* **181**, 1081–1082.

Expansion of primary leaves was accelerated by treatment with gibberellic acid; but the final area attained was identical with that of leaves receiving no treatment. Kinetin (6-furfurylaminopurine), on the other hand, depressed the rate of leaf expansion—an effect which was overcome in the presence of gibberellic acid.

5.6. Humphries, E. C. (1958). The effects of gibberellic acid and kinetin on the growth of Majestic potato. *Ann. appl. Biol.* **46**, 346–351.

The effects of spraying potato plants (var. Majestic) with gibberellic acid and kinetin were investigated. Gibberellic acid increased both leaf area and dry-matter production over the short period of the experiment, but there were indications that this would not persist at maturity. Kinetin alone depressed leaf area and dry-matter production, but this did not occur in the presence of gibberellic acid. The mean net assimilation rate measured over a 2-week period was not significantly reduced by gibberellic acid.

5.7. Monteith, J. L. & (Owen, P. C.) (1958). A thermocouple method for measuring relative humidity in the range 95–100%. *J. sci. Instrum.* **35**, 443–446.

For summary see p. 236 above, no. 1.4.

5.8. Owen, P. C. (1958). The effects of short periods of water stress on the growth of sugar beet in pots. *New Phytol.* **57**, 318–325.

Sugar beet, broad beans and lettuce growing in soil in pots were subjected to repeated short periods of water stress up to a maximum pF of 4·0. In

some experiments the leaf areas of such plants were lower than those of plants grown under conditions of minimum water stress, but there was no significant effect of water stress on dry-matter production or net assimilation rate. The loss of water per unit leaf area was not affected by the water regime, but the cumulative water loss from pot and plant over the experiments was greater under the wet regime, partly because the leaf area was greater. In pot-culture experiments, where the total amount of water within the root zone is relatively small, it is impossible to impose stress conditions above wilting point for long enough to produce detectable effects on growth. The results of water-stress experiments may depend as much on the duration and timing of the periods of stress as on the level of stress imposed.

5.9. Owen, P. C. (1958). The growth of sugar beet under different water regimes. *J. agric. Sci.* **51**, 133–136.

In a small plot experiment in which the crop was protected from rain, the application of large amounts of water to keep the soil water stress to a minimum gave very large crop yields. One-fifth of this amount of water gave 80 per cent of the maximum yield. Small, frequent applications of water appeared to give higher yields than the same amount of water in one large application. Yield differences were due to differences in leaf area rather than in net assimilation rates.

5.10. Thorne, G. N. (1958). Factors affecting uptake of radio-active phosphorus by leaves and its translocation to other parts of the plant. *Ann. Bot. Lond. N.S.* **22**, 381–398.

The rate of uptake of ^{32}P from labelled NaH_2PO_4 solutions sprayed on to one leaf of swedes (*Brassica napus*) or French beans (*Phaseolus vulgaris*) was rapid during the first few hours and fell to zero after 4 days. ^{32}P was detected in the root after 3 hours and continued to move out of the treated leaf for at least 6 days after application. A larger fraction of the applied ^{32}P was absorbed from repeated than from a single spraying.

Swedes absorbed more ^{32}P from a single application to the lower surface than to the upper surface of the leaf. Doubling the concentration of the spray caused a small increase in the percentage of applied ^{32}P that was absorbed. Absorption by French-bean leaves decreased slightly when the area sprayed with a constant amount of ^{32}P was doubled, and decreased with increasing age of leaf. Increasing the phosphorus supply to the roots of swedes affected neither the initial rate nor the total amount of ^{32}P uptake by the leaves, but decreased the quantity of ^{32}P that was translocated out of the treated leaf.

Increasing the relative humidity of the air around the plants also increased ^{32}P uptake. Shading usually decreased uptake and always decreased translocation. Rewetting the leaf to which the ^{32}P had been applied, with water or sucrose solution, had variable effects. The significance of the results is discussed.

Book

5.11. Brenchley, W. E. (revised by Warington, K., 1958). *The Park Grass plots at Rothamsted 1856–1949.* [A revision of *Manuring of grassland for hay*, 1924.] Harpenden: Rothamsted Experimental Station.

Biochemistry Department

General Papers

6.1. Pirie, N. W. (1958). World hunger as a biochemical problem. *J. Roy. Soc. Arts*, **104**, 511–528.

6.2. Pirie, N. W. (1959). *Leaf proteins. Ann. Rev. Plant Physiol.* **10**.

6.3. Pirie, N. W. (1958). Leaves as a source of human food. *Vegan*, **10**, 7–9.

6.4. Pirie, N. W. The properties of fragments of tobacco mosaic virus. *Proc. IV Int. Symp. Biochem.*, 1958. Symp. 7 preprint 7, 1–12.

6.5. Pirie, N. W. Chairman's summing up to the 7th symposium. *Proc. IV Int. Symp. Biochem.*, 1958.

6.6. Pirie, N. W. (1959). Some aspects of the origins of life considered in the light of the Moscow International Symposium. *Int. Coun. Sci. Unions Rev.* **1**.

6.7. Pirie, N. W. (1958). The position of stereoisomerism in argument about the origins of life. *Trans. Bose Inst.*, J. C. Bose Memorial Vol. **22**, 111–120.

6.8. Pirie, N. W. Contribution to the discussion on glutathione. *Biochem. Soc. Symp.* **16**. (In the press.)

Research Papers

6.9. Clarke, A. J. & Mann, P. J. G. (1959). Plant enzyme reactions leading to the formation of heterocyclic compounds. 3. Plant amine oxidase and the formation of pyrrolidine and piperidine alkaloids. *Biochem. J.* **71**, 596–609.

The oxidation of 1 : 4-diaminobutane, 1 : 5-diaminopentane, 1 : 6-diaminohexane and 1 : 10-diaminodecane, catalysed by purified plant amine oxidase preparations in presence of catalase, took place without formation of CO_2. When these oxidations were carried out in presence of β-keto acids CO_2 was formed. The CO_2 outputs sometimes exceeded the O_2 uptakes and arose by decarboxylation of the β-keto acids. The rates of decarboxylation in such systems depended on the amine used as substrate. It was greatest with 1 : 4-diaminobutane and least with 1 : 10-diaminodecane. In manometric experiments evidence was obtained that the decarboxylations were due to stoicheiometric reactions between the β-keto acids and the oxidation products of the amines. The results of paper-chromatographic investigations suggested that the decarboxylations were dependent on condensation reactions between the unsaturated ring compounds, formed by the spontaneous cyclization of the products of oxidation of the amines, and the β-keto acids. This was established by the isolation of *nor*hygrine and *iso*pelletierine from reaction mixtures in which 1 : 4-diaminobutane and 1 : 5-diaminopentane, respectively, were oxidised in presence of acetoacetate. The possible significance of the results in relation to alkaloid biosynthesis is discussed.

6.10. Holden, M. (1957). An investigation on polyphenolic compounds of the cacao leaf in connexion with a chemical method for detecting virus infection. *J. Sci. Fd Agric.* **10**, 553–561.

Polyphenolic substances in acid extracts of cacao leaves have been separated by paper partition chromatography. The substance which gives a red colour when cacao leaf extracts are heated with alkali, a reaction which has been used as the basis of a " colour-test " for detecting infection with swollen shoot virus, has the properties of a *leuco*-anthocyanin. The amount of red-producing *leuco*-anthocyanin varies with the total tannin content of the leaf. In addition to virus infection, other factors, such as age of leaf and variety of cacao, which affect the total tannin content also affect the *leuco*-anthocyanin content. The bearing of this on the applicability of the " colour-test " is discussed.

6.11. Kenten, R. H. (1958). Manometric studies of bracken (*Pteridium aquilinum* (L.) Kuhn) thiaminase. *Biochem. J.* **69**, 439.

The transfer reaction of bracken thiaminase can lead to the production of H^+ ions. Under these conditions it is shown that the reaction can be studied manometrically in bicarbonate–carbon dioxide buffer. When aniline,

piperidine, pyridine and trimethylamine are used as acceptor amines with thiamine in limiting amount, about 5–10 per cent of the thiamine may be lost in side reactions, but there is a reasonable agreement between the calculated and experimental carbon dioxide output. The effect on the rate of bracken thiaminase action of varying the concentration of thiamine and the concentration and type of acceptor amine has been studied.

The manometric method has been used to demonstrate that heteropyrithiamine, quinilino-thiamine, and possibly oxythiamine, are thiaminase substrates. The effect of several structural analogues of thiamine on bracken thiaminase has been studied, and it is shown that 3-(*o*-aminobenzyl)-4-methylthiazolium chloride is a powerful but non-competitive inhibitor.

Conditions are described under which the rate of evolution of carbon dioxide is directly proportional to the amount of bracken-thiaminase preparation present. It is suggested that the manometric method could be used for estimating thiaminase activity.

6.12. Pierpoint, W. S. (1959). Mitochondrial preparations from the leaves of tobacco (*Nicotiana tabacum*). *Biochem. J.* **71**, 518–527.

A succinoxidase preparation was made from tobacco leaves by grinding them in a medium containing sucrose, tris buffer, phosphate, citrate and ethylenediamine tetraacetic acid, and then centrifuging them between 1,000 and 10,000 g. These preparations contained a third of the chlorophyll, 15 per cent of the total protein N and the bulk of the succinoxidase of the extract. The latter was inhibited by malonate and cyanide. The preparations oxidized most of the acids of the tricarboxylic acid cycle; co-factors such as diphosphopyridine dinucleotide, thiamine pyrophosphate and co-enzyme A stimulating some of these oxidations. The products formed during the oxidations of these acids were identified by paper chromatography as other acids of the tricarboxylic acid cycle.

6.13. Pirie, N. W. (1959). The large-scale separation of fluids from fibrous pulps. *J. biochem. microbiol. Technol. & Engng*, **1**.

Most of the free fluid can generally be expressed from fibrous pulps in a few seconds at 50 lb./sq. in. if the layer of pulp is kept thinner than 1 inch after it has been pressed, and if the fluid is allowed to run away freely. The need for this time and the frictional properties of many pulps are serious obstacles to the design of any strictly continuous press. Roller presses do not allow enough time, screw expellers create too much friction, continuous centrifuges and some other arrangements are intricate and vulnerable.

An intermittent but automatic press which avoids these defects is described. In this the material on a perforated conveyor is pressed by a ram and then moved forward as the ram lifts. One such machine has already been made. An outline is given of the principles on which an improved design will depend.

Plant Pathology Department

General Papers and Reviews

7.1. Bawden, F. C. (1958). Viruses and virus diseases (Amos Memorial Lecture). *Rep. E. Malling Res. Sta. for 1957*, 37–42.

7.2. Bawden, F. C. (1959). Physiology of virus diseases. *Ann. Rev. Plant Physiol.*

7.3. Bawden, F. C. (1959). Viruses. (In: *Vistas in Botany.*) London: Pergamon Press Ltd.

7.4. Bawden, F. C. (1959). The multiplication of plant viruses: the establishment and development of infection. (In: *Plant Pathology—Problems and Progress 1908–1958* (Golden Jubilee Meetings, American Phytopathological Society, Bloomington, August 1958.))

7.5. Bawden, F. C. (1959). The multiplication of viruses. (In: *Plant Pathology—A Treatise on Basic Principles*, **2**.) New York: Academic Press, Inc.

7.6. Broadbent, L. (1958). Insect vector behaviour and the spread of plant viruses in the field. (In: *Plant Pathology—Problems and Progress 1908–1958* (Golden Jubilee Meetings, American Phytopathological Society, Bloomington, August 1958).)

7.7. Broadbent, L. (1958). Virus control depends on teamwork. *Farmers Weekly*, Supplement on Sugar Beet and Potatoes (16 May), 18–19.

7.8. Broadbent, L. (1958). Control of virus spread in potato crops. *Outlook Agric.* **2**, 13–15.

7.9. Broadbent, L. (1959). Dispersal of inoculum by insects and other animals, including man. (In.: *Plant Pathology—A Treatise on Basic Principles*, **3**.) New York: Academic Press, Inc.

7.10. Broadbent, L. & Martini, C. (1958). The spread of plant viruses. *Advanc. Virus Res.* **6**, 93–135.

7.11. Buxton, E. W. (1959). Mechanisms of variation in *Fusarium oxysporum* in relation to host–parasite interactions. (In: *Plant Pathology—Problems and Progress 1908–1958* (Golden Jubilee Meetings, American Phytopathological Society, Bloomington, August 1958).)

7.12. Buxton, E. W. (1959). Variability in plant pathogens as a result of heterokaryosis, saltation and adaptation. *Plant Pathology—A Treatise on Basic Principles*, **2**. New York: Academic Press, Inc.

7.13. Harrison, B. D. (1958). Mechanism of transmission of potato leaf roll virus by *Myzus persicae* Sulz. *7th Int. Congr. Microbiol., Stockholm, Abstracts*. pp. 258–259.

7.14. Harrison, B. D. (1959). The multiplication of viruses in plants. (In: *Virus Growth and Variation* (9th Symp. Soc. gen. Microbiol.), 34–60.) Cambridge: University Press.

7.15. Hirst, J. M. (1958). New methods for studying plant disease epidemics. *Outlook Agric.* **2**, 16–26.

7.16. Hirst, J. M. (1958). Apple scab at Wisbech. Achievements and problems after five years research. *Grower & Prepacker*, 15 March, 681–683; 22 March, 741–743.

7.17. Hirst, J. M. (1959). Spore liberation and dispersal. (In: *Plant Pathology—Problems and Progress 1908–1958*) (Golden Jubilee Meetings, American Phytopathological Society, Bloomington, August 1958).)

7.18. Hull, R. (1958). Sugar Beet Yellows. The search for control. *Agriculture, Lond.* **65**, 62–65.

7.19. Kassanis, B. (1958). Viruskrankheiten bei Nelken und ihre Bekämpfung. *Gartenwelt*, **58**, 362–363.

7.20. Watson, Marion A. (1958). The significance of some recent work on aphid and hopper transmitted viruses (Linnean Society Lecture).

7.21. Watson, Marion A. (1959). Cereal virus diseases in Great Britain. *N.A.A.S. Quart. Rev.*

Research Papers

7.22. Badami, R. S. (1958). Changes in the transmissibility by aphids of a strain of cucumber mosaic virus. *Ann. appl. Biol.* **46**, 554–562.

A strain of cucumber mosaic virus isolated from a spinach plant in 1946 was readily transmitted by *Myzus persicae* until 1955 when it lost this property, although it was still being propagated in conditions in which other strains remained transmissible. *Myzus circumflexus* also transmitted other strains but not this one. It was transmitted as readily as other strains by *Aphis gossypii* and *Myzus ascolonicus*. *M. ascolonicus* transmitted less frequently than *A. gossypii*. Transmission of the spinach strain by other aphids did not make it transmissible by *M. persicae*; nor did propagation in different plant species or several passages through spinach. In 1955 the spinach strain was occasionally transmitted by *M. persicae*, but the cultures isolated in this way were no more readily transmissible by the aphid than was the bulk culture maintained by manual inoculation of sap, and after a few weeks all cultures ceased to be transmitted by *M. persicae*.

7.23. Badami, R. S. (1959). Some effects of changing temperature and of virus inhibitors on infection by cucumber mosaic virus. *Ann. appl. Biol.* **47**, 78–89.

Whereas the spinach strain of cucumber mosaic virus fails to multiply and cause symptoms in tobacco plants kept above 30°, the yellow strain infects at 36° and causes more severe symptoms than at 20°. Increasing the temperature up to 28° increases the initial rate at which the spinach strain multiplies, but the virus later reaches much higher concentrations in leaves at lower temperatures, presumably because it is rapidly inactivated at 28°. Exposing inoculated plants to 36° for 6 hours decreases the number of infections by the spinach strain when the exposure starts within 6 hours of inoculation, but not afterwards.

Pancreatic ribonuclease inhibits infections by strains of cucumber mosaic virus; inhibition is greatest when the enzyme is present in the inoculum, and when applied to inoculated leaves its effect decreases rapidly with increasing time after inoculation.

Infection by and the multiplication of strains of cucumber mosaic virus in tobacco are only slightly affected by thiouracil and greatly by azaguanine, whereas strains of tobacco mosaic virus are inhibited much more by thiouracil than by azaguanine. Like tobacco mosaic virus, cucumber mosaic virus multiplies more when inoculated leaves are floated in nutrient solutions than in water, but unlike tobacco mosaic virus, its multiplication is not inhibited by thiouracil more in nutrient solutions than in water.

7.24. Badami, R. S. & Kassanis, B. Some properties of three viruses isolated from a diseased plant of *Solanum jasminoides* Paxt. from India. *Ann. appl. Biol.* (In the press.)

Three mechanically transmissible viruses were isolated from a diseased *Solanum jasminoides* plant obtained from India. One is a strain of potato virus Y, which in some potato varieties produces symptoms resembling those caused by potato virus C, but unlike potato virus C, it is readily transmitted by *Myzus persicae*. The second, named tobacco wilt virus, is also transmitted by *M. persicae* but much less readily, whereas the third, named datura necrosis virus, is not. All three have a wide host range, but neither tobacco wilt nor datura necrosis viruses infect potato plants. All three have long flexuous particles and similar general properties.

Simultaneous infection with datura necrosis virus usually decreases the concentration reached by potato virus Y in tobacco plants but not in *Nicotiana glutinosa*.

7.25. Banks, C. J. & Nixon, H. L. (1958). Effects of the ant, *Lasius niger* L., on the feeding and excretion of the bean Aphid, *Aphis fabae* Scop. *J. exp. Biol.* **35**, 703–711.

For summary see below, no. 10.4.

7.26. Bawden, F. C. (1958). Reversible changes in strains of tobacco mosaic virus from leguminous plants. *J. gen. Microbiol.* **18**, 751–766.

Strains of tobacco mosaic virus (TMV) obtained from systemically infected leguminous plants in Nigeria and India changed their properties greatly when propagated in different hosts. From systemically infected tobacco, they closely resemble type TMV and share many antigens with it, but from systemically infected French bean, they differ from it by at least as much as any previously described strains. The different forms of the viruses share few antigens, have different amino-acid constitutions, electrophoretic behaviour and resistance to inactivation by ultra-violet radiation, and they produce different kinds of local lesion in *Nicotiana glutinosa*. Isolates derived from single local lesions behave like the original bulk cultures, and as the changes are also reversible, they seem unlikely to occur simply because different hosts select different strains from existing mixtures. The electrophoretic patterns, particularly of preparations from beans, show that infected plants contain more than one anomalous product; both forms of the viruses may be produced in all hosts, but there is no evidence that sap from systemically infected beans contains the tobacco forms in amounts needed to cause infection. The change after transfer to a new host apparently occurs because mutants produced in that host are favoured over the infecting form because they move more readily and become systemic. The bean forms multiply more extensively in tobacco at above 30° than at 20°, and above 30° seem not to produce forms that give a systemic mosaic; many tobacco plants at 20° develop only local lesions, and systemic infection, indicating the occurrence of the tobacco forms, happens more often in young seedlings than when mature plants are inoculated.

7.27. Bawden, F. C. & Kleczkowski, A. Some properties of decomposition products of potato virus X. *Virology*. (In the press.)

Its small surface potential probably accounts for the tendency of potato virus X (PVX) to become insoluble during purification. The protein produced by splitting the virus with alkali (about pH 10) has a higher surface potential, electrophoretic mobility in *M*/15 pH 7 phosphate buffer of −0·15 compared with −0·04 μ/second/V/cm. for the virus. The nucleic acid, mobility −1·7, is not infective when it is separated electrophoretically from alkali-split virus. The protein, but not the nucleic acid, precipitates with PVX anti serum. Material with the same electrophoretic mobility as protein produced by splitting the virus with alkali is sometimes detectable in sap from infected plants. Treatments that aggregate protein fragments from tobacco mosaic virus into virus-like rods produce amorphous precipitates of PVX protein that do not redissolve; this difference may reflect the different ways in which surface charges are distributed on the protein from the two viruses. The nucleic acid seems not to contribute to the surface potential of either virus. Disrupting PVX with phenol gives water-soluble material consisting predominantly of nucleic acid; freshly made preparations have some infectivity, which is not conferred by residual intact virus particles.

7.28. Broadbent, L., Burt, P. E. & Heathcote, G. D. (1958). Insecticidal control of potato virus spread. *Proc. 3rd Conf. Potato Virus Diseases, Lisse-Wageningen.*

Replicated trials were done during the years 1955 and 1956 to find out if fewer than the eight sprays of DDT emulsion previously used to limit the spread of leaf roll and Y viruses in Majestic potato crops would be effective, and if low-volume application was as effective as high.

Although aphid control was relatively poor during the hot weather of late summer in 1955, virus control in that year was good. The factors of increase in disease, showing in 1956, from the 0·8 per cent deliberately planted in 1955, were for leaf roll: sprayed eight times, none; six times, 1·5; four times, 2·1; twice, 3·7; and unsprayed 15·3. Comparable figures for rugose mosaic were 6·3, 5·2, 7·3, 9·0 and unsprayed 13·6.

Both aphid control and control of virus spread were good in 1956. Plants were sprayed four or six times at high or low volume. There were no statistically significant differences between treatments: the factors of increase in leaf roll, from the 0·8 per cent planted, averaged 1·6 for sprayed, 7·4 for unsprayed plots, and for rugose mosaic 2·1 for sprayed, 4·9 for unsprayed plots.

The efficiency of the DDT deposits increased as the plant growth-rate decreased. Each year there was an increase in yield in the sprayed plots in comparison with the unsprayed, which roughly equalled the loss in yield caused by the machinery, which damaged the haulms.

An unreplicated trial with King Edward potatoes, on a commercial farm in Essex, tested the control of virus spread achieved by spraying rogued or unrogued areas fortnightly six times with DDT emulsion or endrin. The incidence of virus disease in the untreated area after 3 years was 27 per cent leaf roll and 0·6 per cent rugose mosaic, so this stock was rejected. In the DDT-sprayed area, after 4 years, the incidence of leaf roll was 4·5 per cent, but only 1·5 per cent where this had been rogued; in the endrin-sprayed area there was 7·8 per cent, and 2·9 per cent where rogued. The trial was discontinued after 4 years because virus Y was introduced by aphids during the third year, infecting between 5 and 14 per cent of the tubers in the different sprayed areas.

7.29. Broadbent, L. & Heathcote, G. D. (1958). Properties and host range of turnip crinkle, rosette and yellow mosaic viruses. *Ann. appl. Biol.* **46**, 585–592.

Three isolates of turnip yellow mosaic virus and two other flea-beetle transmitted viruses, turnip crinkle and turnip rosette, have many similar properties: thermal inactivation end-point between 80° and 90° C.; dilution end-point greater than 10^{-4}; longevity *in vitro* at about 20° C. at least 30 days. All were transmitted by mechanical inoculation to a wide range of cruciferous host plants, including many weeds. Turnip yellow mosaic virus infected only *Reseda odorata* outside the *Cruciferae*, whereas rosette virus infected a few and crinkle virus many non-cruciferous hosts.

7.30. Buxton, E. W. (1958). A change of pathogenic race in *Fusarium oxysporum* f. *pisi* induced by root exudate from a resistant host. *Nature, Lond.* **181**, 1222–1224.

Retaining spores of *Fusarium oxysporum* f. *pisi* physiologic race 1 for 14 days in exudates from roots of pea variety Wilt-Resistant Alaska changed their pathogenicity. They became able to act like race 2, in that they wilted this pea variety, having previously been unable to do so. The same result was obtained by repeatedly transferring the spores of race 1 through a series of increasing concentrations of the same root exudate. The same treatments also impaired the ability of race 1 to wilt the susceptible pea variety Onward, for it produced only 73 per cent wilt against the usual 100 per cent by untreated spores. Seven successive inoculations and re-inoculations of the treated spores to variety Wilt-Resistant Alaska failed to change the host-induced increase in pathogenicity.

Changes of this kind, in which physiological activity is altered by an inducing substrate, are common among bacteria, and are generally described as adaptation. It is not known whether the change in pathogenicity described here is a result of selection by the inducing substrate (root exudate) from a resistant plant of randomly occurring mutants, or of the increase by "enzymatic adaptation" of a latent ability to detoxify the exudates from roots of resistant hosts. Mechanisms of this kind, leading to increased host range in a pathogen, whether temporary or permanent, may underly the outbreaks of disease that frequently occur among hitherto resistant host varieties.

7.31. Buxton, E. W., Perry, D. A. (Doling, D. A. & Reynolds, J. D.) The resistance of pea varieties to Fusarium wilt. *Plant Path.* (In the press.)

Tests for resistance to wilt, caused by the fungus *Fusarium oxysporum* f. *pisi*, were made with ninety different pea varieties that are in commercial use in Britain. Replicated plots of each variety, together with control strips of the highly susceptible variety Onward, were sown in wilt-infested fields at Rayne, Essex, and at Yaxley, Peterborough.

Forty-nine per cent of the varieties proved to be wilt-resistant, and nineteen of the susceptible varieties contained a few plants that showed some degree of resistance, resulting from genetic segregation in the parent stocks. Together with observations made in previous years, the reaction to wilt of 143 varieties in this country is now known, and about half are resistant. Unfortunately, pea varieties that are the most popular and in greatest demand are susceptible. There was no correlation between resistance and any morphological characteristic of pea varieties, nor was any particular group of peas, e.g., canners, dried peas, etc., especially resistant.

Comparison with the results of similar field tests reported from Holland and New Zealand show that some varieties have a different reaction to wilt in each locality, probably reflecting an uneven distribution of different pathogenic races of the fungus. In our test areas, races 1 and 3 were prevalent, but there was no evidence of race 2.

Attempts to speed up the classification of pea varieties for wilt-resistance by using artificial inoculation techniques in the glasshouse showed that the only reliable methods can come from using soil from infested fields.

Further progress in combating pea wilt could best be made by breeding resistance into the susceptible commercially popular varieties.

7.32. Chessin, M. (1958). Light quality and photoreactivation of plants and viruses. *Ann. appl. Biol.* **46**, 388–392.

Visible light of different spectral regions was tested for its ability to reverse three effects of ultra-violet radiation, namely, injury (glazing) of French-bean leaves, increased resistance of French-bean leaves to infection by Rothamsted tobacco necrosis virus and inactivation of potato virus X. The different spectral regions were obtained with colorimetric filters and the filtered and unfiltered light from fluorescent tubes; all three effects were reversed only by regions of wavelengths shorter than 4,700 Å. Thirty minutes of illumination at 300–380 f.c. gave substantial photoreactivation, but irradiated potato virus X did not become affected by visible light until 30 minutes after tobacco leaves were inoculated.

7.33. Glynne, Mary D. (1959). Effect of potash on powdery mildew in wheat. *Plant Path.* **8**, 15–16.

The incidence of powdery mildew *Erysiphe graminis* on wheat grown on certain Broadbalk plots was measured by estimating the percentage area of the top two leaves covered by mildew pustules. The disease was most severe on plots receiving nitrogen and phosphate but no potash; was more severe in the first than the third crop after fallow, and was least in plots receiving potash.

7.34. Glynne, Mary D. & Slope, D. B. (1959). Effects of previous wheat crops, seed-rate and nitrogen on eyespot, take-all, weeds and yields of two varieties of winter wheat. *Ann. appl. Biol.* **47.**

In a replicated field experiment mean yields of wheat from plots that, in the preceding 2 years, had carried oats, beans or potatoes were 39·2 and 42·6 cwt./acre in 1954 for Holdfast and Cappelle respectively; 42·8 and 55·8 in 1955 and 34·9 and 49·6 in 1956. Previous wheat crops had more effect than any other treatment in increasing the incidence of eyespot, take-all and weeds and in decreasing the number of ears per unit area and the yield of grain. In 1956 on plots carrying the first, second and third successive wheat crops the percentage of straws with eyespot were respectively 12, 54 and 42 and with take-all 0·1, 1 and 16. Cappelle was less severely infected by eyespot than Holdfast. The second and third successive wheat crops yielded an average of 23·3 cwt./acre less than the first wheat crop. Cappelle consistently yielded more than Holdfast, the mean difference being 13·8 cwt./acre after potatoes

but only 3·8 cwt./acre after two wheat crops. The higher seed-rate gave an average increase in grain yield of 3·3 cwt./acre; but where eyespot and take-all were both severe, the lower seed-rate yielded as much total and more dressed grain than the higher. Wheat given a spring top dressing of 6 cwt./acre " Nitro-chalk " yielded an average of 4 cwt./acre more grain than wheat given 3 cwt./acre.

7.35. Gregory, P. H. & Stedman, O. J. (1958). Spore dispersal in *Ophiobolus graminis* and other fungi of cereal foot rots. *Trans. Brit. mycol. Soc.* **41**, 449–456.

During October 1953 air was sampled with a Hirst (1952) automatic volumetric spore trap at a height of 0·5 m. above the stubble of a wheat crop bearing fructifications of *Ophiobolus graminis*, *Cercosporella herpotrichoides* and *Fusarium culmorum*. Exposed slides were scanned under the microscope in positions corresponding to 2-hourly intervals, to estimate the concentrations of various spore types. Ascospores of *O. graminis* were never caught on rainless days; nor after rain of less than 0·01 inch. They were caught within an hour of 0·01 inch or more rain, and attained a maximum concentration of 3,700/cu. m. of air within 2 hours of rain of 0·05 inch. Wind-tunnel tests showed that the peak rate of liberation occurred within 45 minutes of wetting. All mature ascospores seemed to be discharged during 4 hours of rain, but a few dry days sufficed for another batch to mature. *C. herpotrichoides* behaved differently: a few conidia occurred after a trace of rain, and more rain did not increase their numbers; their maximum concentration was only one-tenth of *O. graminis*. Concentrations of coloured basidiospores were constant, regardless of weather and time of day, and *Cladosporium* was more common by day than by night. No macroconidia of *Fusarium* were detected.

7.36. Heathcote, G. D. & Ward, J. (1958). The preference shown by *Myzus persicae* (Sulz.) for *Brassica* plants sprayed with wetting agents. *Bull. ent. Res.* **49**, 235–237.

For summary see below p. 260, no. 9.9.

7.37. Hirst, J. M. & Salt, G. A. *Oospora pustulans* Owen and Wakef., as a parasite of potato root systems. *Trans. Brit. mycol. Soc.* (In the press.)

A fungus isolated from brown lesions in the cortex of root systems of Majestic potatoes at Rothamsted in 1951 was identical morphologically with *Oospora pustulans*, the cause of skin-spot disease of tubers. The pathogenicity of *O. pustulans* from tubers for root systems of potato and tomato was demonstrated. Tuber yield was not greatly affected despite severe damage to the roots, and the chief importance of root infection may be to provide sources of infection for progeny tubers or subsequent potato crops.

The infection of root systems, prevalent at Rothamsted each year, does not obviously depend on previous potato cropping, or on the presence of macroscopic skin-spot symptoms on the seed tubers. Observations suggest that eye infections, which may not be detected by macroscopic examination, are common and that soil-borne fungus is probably less important in leading to outbreaks of skin-spot than fungus on the seed tubers. Test with tomato seedlings should help to determine how long *O. pustulans* survives in soil.

7.38. Kassanis, B. & Slykhuis, J. T. Some properties of barley stripe mosaic virus. *Ann. appl. Biol.* (In the press.)

Barley varieties differed greatly in their reactions to infection with barley stripe mosaic virus (BSMV) obtained from the variety Gloire du Velay growing in Cambridgeshire from seed imported from France. *Lolium multiflora* Lam. previously considered immune, proved susceptible, as did *Beta vulgaris* L. and *Chenopodium amaranticolor* Corte & Reyn., which gave only local lesions, and *Spinacea oleracea* L., which became systemically infected.

Heating at 65° C. for 10 minutes destroyed the infectivity and serological activity of BSMV. Sap was still infective after 32 days at 20° C., but lost its infectivity and half of its serological activity in 3 days at −20° C.; adding sugar to the sap prevented inactivation by freezing. The virus content of inoculated barley leaves increased most rapidly in plants kept at 24° to 28° C.

At 24° C. increase was most rapid during the first 5 days, and the maximum virus concentration was reached about 10 days after inoculation. The highest infection end-point of sap was 1/2048, when the precipitation end-point with virus antisera was 1/256, and sap contained 10^{13} virus particles/ml.; the ratio of infectivity to serological activity and to number of virus particles is much smaller than with tobacco mosaic virus.

The rod-shaped particles are about 20 mμ wide and, in fresh sap, most are between 135 and 175 mμ long. Various treatments, especially heating to 50° C., cause the particles to aggregate linearly. Preparations partially purified by alternate cycles of low- and high-speed centrifugation and by precipitation with ammonium sulphate contain from 0·35 to 0·53 per cent P, 12·3 to 13·2 per cent N and 6·2 to 10·2 per cent carbohydrate. Such preparations are insoluble in water but dissolve in borate buffer at pH 7·5; they inactivate below pH 4·5.

7.39. Macfarlane, I. (1958). A solution-culture technique for obtaining root-hair, or primary, infection by *Plasmodiophora brassicae*. *J. gen. Microbiol.* **18**, 720–732.

Primary infections were obtained by growing cabbage seedlings in a modified Hoagland's solution in which resting spores of *Plasmodiophora brassicae* Woron. were suspended. Seeds were germinated on filter-paper wet with tap water, and after 2 days the plants were transferred to small glass tubes bent in the form of a shallow U or to small vials containing solution and spores. Zoosporangia were formed after several days growth at 25° in the dark. They were stained in acetocarmine. A roughly linear relationship was found between the logarithm of number of infections/root and the logarithm of spore concentration in the medium. Numbers of infections were usually greater at $\frac{1}{5}$ or $\frac{1}{25}$ dilution of the culture solution than at the standard concentration, but were very much fewer or none in more dilute $\frac{1}{125}$ or more concentrated (×5) solutions. The concentration which permitted maximal infection tended to vary from one experiment to another. Infection was not affected by changing from pH 5 to 6, but was greatly decreased at pH 8.

7.40. Salt, G. A. (1959). Effects of nitrogenous fertilizer applied at different dates on take-all, eyespot and yield of winter wheat grown on light sandy loam. (Field experiments 1954, 1955, 1956.) *Ann. appl. Biol.* (In the press.)

In a replicated field experiment on light, sandy loam at Woburn, where winter wheat is a very uncertain crop, Cappelle and Holdfast grown after potatoes with dung yielded 50 and 41 cwt./acre of grain respectively when given 6 cwt./acre of "Nitro-chalk" in April, compared with 19 and 20 cwt./acre when unfertilized. The same fertilized plots yielded 29 and 19 cwt./acre respectively in the second, and 25 and 17 cwt./acre respectively in the third year on the same land, whereas unfertilized plots of both varieties yielded only 9 cwt. and 5 cwt./acre. The decrease in mean yield from 27 cwt./acre in the first, to 15 and 10 cwt./acre in the second and third crops was associated with a decrease in ear number from 16·7 to 14·6 and 12·2 respectively, and with a striking decrease in weight of grain per ear, caused partly by a large increase in the proportion of small grains. Eyespot (*Cercosporella herpotrichoides* Fron.), although present each year, did not become prevalent; an increase in the percentage straws affected by take-all (*Ophiobolus graminis* Sacc.) from 9 to 15 and 26 per cent respectively, and a severe increase in weed infestation (*Agrostis gigantea*) appeared to be the main factors reducing yield.

"Nitro-chalk" applied in April yielded most grain every year, and wheat fertilized at this time had less eyespot and take-all than that fertilized in March. Fertilizer applied in May increased weed growth, failed to decrease take-all and yielded fewer ears, less grain and a higher proportion of tail corn than did earlier applications.

7.41. Salt, G. A. (1959). Eyespot of wheat in ley–arable rotation experiments at Rothamsted (1952–1958). *Plant Path.* **8.**

The incidence of soil-borne diseases in winter wheat (var. Yeoman), under different ley–arable rotations was compared in the ley–arable rotation experiments at Rothamsted, where the arable sequence wheat–potatoes–barley

follows 3 years of grazed ley, cut grass, lucerne and the arable crops hay–potatoes–barley (later oats). In the 4 years 1952–55 eyespot (*Cercosporella herpotrichoides*) was prevalent in wheat after arable crops but not after any of the leys. The percentage of infected straws on Highfield (old pasture) and Fosters (old arable land) ranged from 6·3 and 6·4 to 43·2 and 90·3 per cent respectively after arable crops and from 0·2 and 1·2 to 4·2 and 14·7 per cent respectively after the leys. Oats, a much less susceptible crop, was substituted for barley in 1955, and consequently in the last 3 years there has been very little eyespot in any of the four rotations.

There was take-all (*Ophiobolus graminis*) on a few wheat straws after barley in one year, and none after grass or lucerne. Sharp eyespot lesions caused by *Rhizoctonia* (*Corticium*) *solani* occurred each year, and the percentage of infected straws, similar in all the rotations, ranged from 0·5 to 15·7 per cent in different years.

7.42. Slykhuis, J. T. & Watson, Marion A. 1958. Striate mosaic of cereals in Europe and its transmission by *Delphacodes pellucida* (Fab.). *Ann. appl. Biol.* **46**, 542–553.

A virus disease that resembles wheat striate mosaic was found affecting up to 5 per cent of the plants in English wheat fields in 1956. Symptoms on wheat included fine chlorotic striae, followed by stunting, general chlorosis and death of plants. Other hosts included oats, barley, rye, perennial ryegrass and Italian ryegrass.

The virus was transmitted by *Delphacodes pellucida* (Fabricius) (Homoptera, Araeopidae). A few of the insects were already infective when caught in the field. The percentage of infective individuals was increased by feeding the insects for 24 hours or longer on diseased plants, and up to 56 per cent became infective after feeding on diseased plants for 3 days. Non-infective insects were unable to transmit the virus until from 8 to 36 days after they first fed on diseased plants, but they frequently remained infective for the remainder of their lives, up to 10 weeks after feeding on a diseased plant. Infective insects seldom transmitted the virus during test feeds as short as 30 minutes. When fed for 1 or more days on each test plant some insects infected many plants in succession, others seldom infected test plants even if they fed as long as 7 days on each. The virus was transmitted through the eggs to as many as 88 per cent of the progeny of infective females, and to some of the progeny of a few females that had failed to infect wheat test plants.

Nematology Department

General Papers

8.1. Doncaster, C. C. (1959). High-speed flash photography of soil animals. (In: *Research methods in soil zoology*. Ed. P. W. Murphy.) London: Butterworth.

8.2. Doncaster, C. C. (1959). Cinematography of soil animals. (In: *Research methods in soil zoology*. Ed. P. W. Murphy.) London: Butterworth.

8.3. Fenwick, D. W. (1959). The genus *Heterodera*. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture, Tech. Bull. No. 7.) London: H.M.S.O.

8.4. Fenwick, D. W. (1959). Estimation of soil populations: principles and techniques. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.5. Fenwick, D. W. (1959). Root diffusates and the hatching process in *Heterodera* spp. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.6. Franklin, M. T. (1959). Root-knot nematodes, *Meloidogyne* spp. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.7. Franklin, M. T. (1959). Plant parasitic nematodes of the genus *Aphelenchoides* Fischer 1894. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture, Tech. Bull. No. 7.) London: H.M.S.O.

8.8. Goodey, J. B. (1959). Preparation of nematodes for microscopic examination. (In: *Research methods in soil zoology*. Ed. P. W. Murphy.) London: Butterworth.

8.9. Hesling, J. J. (1959). The identification of *Heterodera* cysts. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.10. Jones, F. G. W. (1957). Principles of population estimation. (In: *Proceedings of the S.19 Workshop in Phytonematology* Ed. E. J. Cairns. Univ. Tennessee. Popul. 1–11.)

8.11. Jones, F. G. W. (1957). Heterodera: life history, trends, host ranges, ecology, population studies, root diffusates. (In: *Proceedings of the S.19 Workshop in Phytonematology*. Ed. E. J. Cairns, Univ. of Tennessee. Heter. 1–13.)

8.12. Jones, F. G. W. (1957). Breeding and resistance to potato root eelworm, *Heterodera rostochiensis*, Woll. (In: *Proceedings of the S.19 Workshop in Phytonematology*. Ed. E. J. Cairns. Univ. Tennessee. Res. (Heter.): 1–17.)

8.13. Jones, F. G. W. (1957). Entomology and Nematology in the School of Agriculture, 1899–1956. *Mem. Camb. Sch. Agric.* **29**, 5–11.

8.14. Jones, F. G. W. (1958). Aspects of nematology in Great Britain. *Agric. Rev. Lond.* **3**, 8–19.

8.15. Jones, F. G. W. (1959). Ecological relationships of nematodes. (In: *Golden Jubilee Volume, American Phytopathological Society*.) (In the press.)

8.16. Jones, F. G. W. (1959). An introduction to plant nematology. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.17. Jones, F. G. W. (1959). Beet eelworm and other root eelworms. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7). London: H.M.S.O.

8.18. Murphy, P. W. & Doncaster, C. C. (1959). A culture method and accessory techniques for soil micro-arthropods. (In: *Research methods in soil zoology*. Ed. by P. W. Murphy.) London: Butterworth.

8.19. Wallace, H. R. (1958). The control of eelworms. *Diamond Fields Advertiser* (Kimberley, S. Africa.)

8.20. Wallace, H. R. (1959). A study of the movement of eelworms in relation to some physical properties of soil. (In: *Research methods in soil zoology*. Ed. P. W. Murphy.) London: Butterworth.

8.21. Wallace, H. R. (1959). The influence of soil conditions on larval emergence and movement. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No 7.) London: H.M.S.O.

8.22. Widdowson, E. (1959). The conduct of hatching tests. (In: *Plant nematology*. Ed. J. F. Southey. Ministry of Agriculture Tech. Bull. No. 7.) London: H.M.S.O.

8.23. Widdowson, E. (1959). Techniques for culturing *H. rostochiensis* Woll. in excised tomato roots. (In: *Research methods in soil zoology*. Ed. by P. W. Murphy.) London, Butterworth.

8.24. Widdowson, E. (1959). The estimation of soil populations of the potato root eelworm. (In: *Research methods in soil zoology*. Ed. by P. W. Murphy.) London, Butterworth.

8.25. Winslow, R. D. (1958). Eelworm control. Some aspects of past and present research. *Agriculture, Lond.* **65**, 66–69.

Research Papers

8.26. Fenwick, D. W. & Widdowson, E. (1958). The conduct of hatching tests on the potato root eelworm *H. rostochiensis*. *J. Helminth.* **32**, 125–134.

Methods for the collection and the preliminary assay of both cysts and diffusate for hatching experiments are set out. The general principles of the hatching-test technique are examined and show how experiments can be designed to give predetermined levels of accuracy. The interpretation of the results of a test falls into two parts, the estimation of the activity of the samples under tests and the analysis of the data to verify that the levels of accuracy obtained in the preliminary assays still apply.

8.27. Goodey, J. B. (1958). *Paraphelenchus myceliopthorus* n.sp. (Nematoda: Aphelenchidae). *Nematologica*, **3**, 1–5.

Paraphelenchus myceliopthorus n.sp. is described and figured. The nematode attacks the mycelium in compost of cultivated mushroom beds. The excretory duct joins the pore to a ventral uninucleate cell. [Further examination shows that the duct continues in the lateral field beyond the cell.] The species is characterized by the pattern of the papillae on the male tail and the absence of a mucron on the female tail.

8.28. Goodey, J. B. (1958). *Ditylenchus myceliophagus* n.sp. (Nematoda: Tylenchidae). *Nematologica*, **3**, 91–96.

Ditylenchus myceliophagus n.sp., which destroys mushroom mycelium, is described and figured. It differs morphologically from its nearest relative *D. destructor* in the broader finger-like tails of both sexes, in the shape of the spicules and the shorter post-vulval sac.

8.29. Goodey, J. B. (1958). *Sphaeronema minutissimum* n.sp. (Sphaeronematinae: Tylenchulidae). *Nematologica*, **3**, 169–172.

Sphaeronema minutissimum n.sp. is described and figured. Females and larvae were found on the roots of *Citrus* sp. The female body is almost spherical and about 66 μ in diameter, with an offset neck and head. The lip region has a circum-oral elevation and the egg is almost spherical. The nematode is placed in *Sphaeronema* with certain reservations.

8.30. Goodey, J. B. & Hooper, D. J. (1958). Observations on the effects of *Ditylenchus dipsaci* and *Anguina tritici* on certain wheat and barley varieties. *Nematologica*, **3**, 24–29.

Following the report in 1954 by Belloni that in Italy, *Triticum aestivum* L. was attacked by *Ditylenchus dipsaci*, varieties of wheat, barley and rye were tested for their reactions to *D. dipsaci*, derived from oats in Britain, and *Anguina tritici*. No variety of any cereal was attacked by *D. dipsaci*, but all the wheats, including several Italian varieties, were susceptible to *A. tritici*. It appears that the race of *D. dipsaci* attacking wheat in Italy is biologically different from the oat race of Britain. In Britain there is at present no real danger of attack by *D. dipsaci* on wheat or barley. Resistance of wheat to *D. dipsaci* does not infer resistance to *A. tritici*.

8.31. Hesling, J. J. (1958). The efficiency of certain grasses as hosts of the cereal-root eelworm *Heterodera major*. *Plant Path.* **7**, 141–143.

Cocksfoot, *Dactylis glomerata*, timothy, *Phleum pratense*, perennial ryegrass (*Lolium perenne*) and Italian ryegrass (*L. italicum*) were grown in pots of soils with different infestation levels of the cereal-root eelworm *Heterodera major*. Timothy is a very poor host. Although the other grasses increased the eelworm population, the increase was small compared with that caused by oats grown under similar conditions, and no significant differences in the host efficiency of these grasses could be shown.

8.32. Hesling, J. J. (1958). *Heterodera major*—population changes in the field and in pots of fallow soil. *Nematologica*, **3**, 274–282.

In fields on chalky soil in Hampshire and in fields on sandy soil in the West Midlands the cereal-root eelworm (*Heterodera major*) population increased when barley was grown, but decreased when grasses and non-host crops were grown. Frequent examination of infested fallow soil over a 2-year period showed that the eelworm population fell to about 40 per cent of its original value between March and mid-July; during the rest of the year there was little change. Barley sown in this soil at the end of the 2-year period produced large numbers of cysts.

8.33. Hooper, D. J. (1958). *Aphelenchoides dactylocercus* n.sp. and *A. sacchari* n.sp. (Nematoda: Aphelenchoidea). *Nematologica*, **3**, 229–235.

The two new species *Aphelenchoides dactylocercus* and *A. sacchari* are described. The former is characterized by its narrow, finger-like tail and short, post-vulval sac. The latter is characterized by its rather short oesophagus, short female tail and the shape and small size of the spicules in the male. Both species have three incissures on the lateral field. These two species are fungivorous and are easily cultured on mushroom mycelium (*Agaricus hortensis* Cooke).

8.34. Jones, F. G. W. (1958). Resistance-breaking populations of potato-root eelworm. *Plant Path.* **7**, 24–25.

Further tests on twenty-five populations of potato-root eelworm were made. The results confirmed previous findings, namely that many populations contain biotypes capable of breaking the resistance of hybrids containing the gene H derived from *Solanum tuberosum* ssp. *andigena*. *Solanum vernei* proved resistant to all populations tested.

8.35. *Shepherd, A. M. (1958). Experimental methods in testing for resistance to beet eelworm, *Heterodera schachtii* Schmidt. *Nematologica*, **3**, 127–135.

After a short review of previous work on testing for resistance to beet eelworm, experiments on the variability arising in techniques for such tests are described. In pot tests with sugar beet, the variation in the number of cysts on plants of the same line under standard conditions is very high for all

* Work begun in the School of Agriculture, University of Cambridge.

methods of inoculating, making detection of small differences in resistance impossible. Also, seasonal conditions affect cyst production. A technique for routine screening for resistance, involving the addition of hatched larvae to seedlings in small pots, is described. Selection for tolerance to attack, and the possible occurrence of resistance-breaking biotypes are also discussed. Because of the great variation encountered in pot tests, the necessity for careful planning of experiments and care in interpretation of results where such techniques are used, is stressed.

8.36. WALLACE, H. R. (1958). Movement of eelworms. II. A comparative study of the movement in soil of *Heterodera schachtii* Schmidt and of *Ditylenchus dipsaci* (Kühn) Filipjev. *Ann. appl. Biol.* **46**, 86–94.

Studies of mobility in horizontal tubes containing different soil fractions at different suctions and in single layers of particles, showed that the optimum particle size for movement of *Heterodera schachtii* and *Ditylenchus dipsaci* was 150–250 and 250–500 μ, respectively. In both species mobility was greatest when: (*a*) there were few pores smaller in diameter than the eelworm width; (*b*) the pore diameter was narrow enough to restrict lateral movement; (*c*) the tortuosity of the channels between particles was such that the body form of the eelworm had waves of long wavelength and short amplitude. By plotting tracks among water droplets it was possible to show quantitatively the relationship between the form of the body waves and the speed of the eelworms. The optimum temperature for movement was 15° C., for *H. schachtii* and 15–20° C. for *D. dipsaci*. The comparative study suggested that there was a simple relationship between body length, particle size and speed.

8.37. WALLACE, H. R. (1958). Movement of eelworms. III. The relationship between eelworm length, activity and mobility. *Ann. appl. Biol.* **46**, 662–668.

Tracks were plotted of about 300 individual eelworms comprising six species among water droplets on a glass surface. Measurements of the tracks indicated that the product of length and activity of an eelworm divided by its speed was a constant. This supports the hypothesis that the speed of an eelworm among water droplets is a function of its length and activity. The principle can be applied only to movement in soil where the length of the eelworm is less than about three times the particle diameter. Under such conditions the eelworms move in thin films or water droplets over particles. Among smaller-sized particles the speed of the eelworms is influenced by particle size. With increasing eelworm length there is an increase in soil particle size for maximum mobility.

8.38. WALLACE, H. R. (1959). Movement of eelworms. IV. The influence of water percolation. *Ann. appl. Biol.* **47**. (In the press.)

The relationship between rate of flow of water through sands of different particle size and the downward velocity of eelworms of various lengths and activities is not linear. For rates of flow less than about 500 cm./hour the velocity of the eelworms relative to the velocity of water is greater than for flow rates greater than about 500 cm./hour. For rates of flow greater than 500 cm./hour an equation is derived which relates velocity of eelworms, rate of water flow, length of eelworms and pore diameter in the sand. The velocity of the eelworms increases as pore diameter increases; the velocity approaches zero when the eelworms' length exceeds four times the pore diameter; the relationship between velocity of eelworm and velocity of water is independent of the eelworm's own activity; the equation of eelworm movement is valid for both continuous and discontinuous saturated flow. With flow rates less than about 500 cm./hour, the velocity of the eelworms increases as the eelworms' activity increases, and eelworms appear to pass through smaller pores than at high flow rates. Dead or inactive eelworms do not progress very far in sand even at high flow rates, and observations suggest that slight flexing movements of the eelworm body are essential for passage.

8.39. WALLACE, H. R. (1958). Observations on the emergence from cysts and the orientation of larvae of three species of the genus *Heterodera* in the presence of host plant roots. *Nematologica*, **3**, 236–243.

Much work has been published on the influence of root diffusates on the emergence *in vitro* of larvae from cysts of different species of the genus *Heterodera*. There are also numerous references in the literature to larval emergence in the soil in the presence of host and non-host plants. There is, however, little information about larval emergence in the presence of plants where there is control of the environmental conditions. The question whether larvae of the genus *Heterodera* are attracted to roots has also received little attention, the only work in this connection being on the related genus *Meliodogyne* (Wieser 1955, 1956). The work herein described is an attempt to show how pressure deficiency (or suction) and moisture content in sand influence the rate of larval emergence from cysts of *Heterodera major* O. Schmidt, *H. schachtii* Schmidt and *H. rostochiensis* Wollenweber. The influence of the host plant on this relationship is examined and the problem of attraction of larvae to roots has also been studied.

8.40. WIDDOWSON, E. (1958). The production of root diffusate by potatoes grown in water culture. *Nematologica*, **3**, 108–114.

Potato plants (variety Arran Banner), were grown in 1 litre of plant nutrient solution, in tap water, and in distilled water, in black jars of 125 ml. capacity. The growth compared favourably with that of potatoes grown in pots of sand, but for at least the first 4 weeks of growth diffusate production was lower. No advantage was found in allowing diffusate to build up in the jars for several days, since it was possible to increase output during the later stages of growth by giving fresh nutrient solution every 1 or 2 days either by root or as a foliar spray.

8.41. WIDDOWSON, E. (1958). Some observations on the collection and storage of potato-root diffusate. *Nematologica*, **3**, 173–178.

Leaching Arran Banner potatoes with varying volumes of water showed that about 50 ml. of an active root diffusate can be taken thrice weekly from a plant in a 6½-inch pot. No increase in the yield of hatching factor resulted after heavier leaching. A mixture of three parts of loam to one of sand was a suitable mixture for growing potatoes for diffusate collection in the greenhouse, plants grown in sand were less vigorous, even with the addition of a plant nutrient. Samples of the same stock of a root diffusate broke down at a variable rate when stored separately, so that it is advisable to pool together all samples of a suitable activity and to store in bulk. Weekly assays of such bulk stocks stored at a temperature of 3–5° C. showed that activity remained stable for several months.

8.42. WIDDOWSON, E., DONCASTER, C. C. & FENWICK, D. W. (1958). Observations on the development of *Heterodera rostochiensis* Woll. in sterile root cultures. *Nematologica*, **3**, 308–314.

Details are given of techniques for setting up aseptic infestations of potato-root eelworm larvae in root tissues. The roots were grown in 0·75 per cent nutrient agar in test-tubes and eelworm eggs surface sterilized with 20 vols. H_2O_2 were added. Four or five days after inoculation, groups of active larvae were seen around the root tips, and maximum invasion usually occurred within 21 days of inoculation.

The parasites appeared to develop normally inside the tissues to adult males and virgin females. No free males were found, and none of the adult females examined contained eggs.

8.43. WIDDOWSON, E. & WILTSHIRE, G. H. (1958). The potato-eelworm hatching factor. *Ann. appl. Biol.* **46**, 95–101.

Root diffusate leached from pots of Arran Banner potatoes was acidified and extracted with powered charcoal. The factor was removed from the charcoal by elution with acetone. Some purification was achieved by transferring

the active material from acid solution to butanol and then to bicarbonate. Stability tests, paper electrophorosis, ion exchange and chromatographic studies were made on such a preparation.

8.44. Winslow, R. D. (1958). The taxonomic position of *Anguillulina obtusa* Goodey, 1932 and 1940. *Nematologica*, **3**, 136–139.

Nematodes obviously identical with *Anguillulina obtusa* Goodey, 1932 and 1940 have been recovered from Rothamsted turf. Goodey believed this nematode to be identical with *Tylenchus obtusus* Bastian 1865, but the latter nematode is insufficiently described and figured to justify this, hence the specific name "*obtusa*" is invalid. Goodey's nematode is very close to *Pratylenchus* but didelphic, and the writer proposes for it the new generic and specific names *Pratylenchoides crenicauda*.

Insecticides and Fungicides Department

General Papers

9.1. Broadbent, L., Burt, P. E. & Heathcote, G. D. (1957). Insecticidal control of potato virus spread. *Proc. 3rd Conf. Potato Virus diseases, Lisse-Wageningen*, 91–105.

For summary see above page 248, No. 7.28.

9.2. McIntosh, A. H. (1958). Dipping methods. (In: *Methods of testing chemicals on insects.* Ed. H. H. Shepard. **1**, 130–153.) Minneapolis: Burgess Publishing Co.

9.3. Potter, C. & Way, M. J. (1958). Precision spraying. (In: *Methods of testing chemicals on insects.* Ed. H. H. Shepard, **1**, 154–258.) Minneapolis: Burgess Publishing Co.

9.4. Way, M. J. (1956). A case for field beans. *Agriculture, Lond.*, **64**, 57–59.

9.5. Way, M. J. (1958). The influence of other ant species on biological control of *Oecophylla longinoda* (Latr.). *Proc. 10th Inter, Cong. Ent., Montreal*, **4**, 595–596.

Research Papers

9.6. Bardner, R. (1958). Seed dressings for the control of wheat-bulb fly. *Plant Path.* **7**, 125–129.

Twenty-seven different insecticides were tested as seed dressings. Treated seeds were sown in boxes of soil containing wheat-bulb fly eggs. Each insecticide was tested at two of three possible levels of application, viz. 0·04, 0·15 and 1 per cent of seed weight. No material was better than heptachlor at 1 per cent, but the following materials were comparable: γ-BHC (0·15 per cent), parathion (0·15 per cent), chlordane (1 per cent), endrin (1 per cent), isodrin (0·15 per cent and 1 per cent), dieldrin (0·15 per cent and 1 per cent) and DDT (0·04 per cent). Parathion and γ-BHC were phytoxic at these concentrations. No material gave complete protection, but the most successful treatments reduced the number of damaged stems by 50–70 per cent compared with untreated controls.

9.7. Bardner, R. & Kenten, Joyce (1957). Notes on the laboratory rearing and biology of the wheat-bulb fly, *Leptohylemyia coarctata* (Fall.). *Bull. ent. Res.* **48**, 821–831.

The laboratory rearing of all stages in the life-history of the wheat-bulb fly, *Leptohylemyia coarctata* (Fall.), is described. The object of this work was to provide suitable material, in particular eggs and larvae, for insecticide experiments. Details of a container suitable for ovipositing adults are given.

Several diets for the adults were compared, and it was found that the greatest number of eggs was produced when the flies were fed on beef blood and a mixture of sweetened condensed milk and honey. Females were found to lay up to 244 eggs each; egg-laying commences 9–15 days after emergence and continues almost as long as the females live, but reaches a peak 3–5 weeks after emergence. Some females survived from late June until early November. In a small laboratory population the average number of eggs laid by each female was 29·9 and mean length of life was 26·3 days for males and 41·6 days for females.

The eggs have a long obligatory diapause period. They have no effective water-proofing mechanism, but can recover from considerable temporary desiccation. A method of storage during diapause is described. The eggs normally hatch in late January or early February, but hatching can be delayed until much later in the year by storage below 0° C.

The effects of temperature on larval and pupal development are described. Larvae will grow at 20° C., but pupating larvae or young pupae are rendered sterile unless kept at temperatures of 15° C. or below. It is shown how a combination of delayed hatching and rapid larval and pupal development can produce fertile flies at unusual times of the year in the laboratory. It is suggested that this may make it possible to produce young larvae in the autumn for insecticide experiments.

In conclusion, some parasites and predators encountered in the field and the laboratory are mentioned.

9.8. Elliott, M. (1958). Isolation and purification of (+)-pyrethrolone from pyrethrum extract: reconstitution of pyrethrins I and II. *Chem. & Ind.* 685–686.

Pyrethrolone and cinerolone, the alcoholic components of the insecticidal esters in pyrethrum extract, were regenerated from their semicarbazones by shaking with dilute sulphuric acid. (+)-Pyrethrolone mono-hydrate is crystalline; it was purified by recrystallisation from ether. This pyrethrolone, purer than earlier specimens, was used to produce and characterize pyrethins I and II by esterification with naturally derived chrysanthemic and pyrethric acids.

9.9. Heathcote, G. D. & Ward, J. (1958). The preference shown by *Myzus persicae* (Sulz.) for *Brassica* plants sprayed with wetting agents. *Bull. ent. Res.* **49**, 235–237.

Insecticide formulations for spraying crops usually contain agents to disperse the insecticide and improve the wetting of the foliage. During a series of experiments to study the response of aphids to leaves sprayed with insecticide, it was noticed that more aphids often occurred on leaves which had been sprayed with a solution of wetting agent than occurred on unsprayed leaves. This paper gives evidence from these experiments for wetting agents seeming to attract aphids, and describes other experiments done specifically to investigate the question.

9.10. Last, F. T. (1958). Stem infection of cotton by *Xanthomonas malvacearum* (E.F.Sm.) Dowson. *Ann. appl. Biol.* **46**, 321–335.

Varying the position of stem inoculation, the concentration of inoculum and the age of plant affected the reaction of cotton, *Gossypium* sp., to infection with *Xanthomonas malvacearum* (E.F.Sm.) Dowson.

The extent of stem discoloration, internal and external, and the probability of disease occurring in leaves by bacteria moving within the plant increased (*a*) the nearer the point of stem inoculation was to the apex, and (*b*) the higher the concentration of inoculum. The leaf symptoms were not the angular spots typical of primary leaf infection. Instead, bacteria seemed to lodge in, discolour and blacken sections of leaf veins. Then tissue next to the affected veins became water-soaked and leaf sectors dependent upon these veins died and dried. These symptoms usually developed 14 to 55 days after inoculation in the expanding leaves.

The amounts of stem discoloration and the probabilities of leaf symptoms developing were less when hypocotyls of old plants were inoculated than when hypocotyls of young plants were inoculated. The probabilities of leaf symp-

toms developing were similar, however, when young tissues in young and old plants were inoculated.

American cotton, *Gossypium hirsutum*, was less affected by stem inoculation than Egyptian cotton, *G. barbadense*. Of the resistance factors against primary leaf infection only B_{6m} gave appreciable stem resistance.

9.11. LAST, F. T. & (DRANSFIELD, M.) (1959). Measurement of the resistance of cotton to *Xanthomonas malvacearom* (E.F.Sm. Dowson) using a leaf abrasion technique. *Emp. Cott. Gr. Rev.*

The numbers of lesions (angular leaf spots) per unit area and their rates of development were assessed on a range of cottons after abrading leaves with carborundum and then rubbing with a suspension of *Xanthomonas malvacearum*. Fewer lesions developed (1) on American cottons, *Gossypium hirsutum*, than on Egyptian cottons, *G. barbadense*, and (2) on varieties with resistance factors than on fully susceptible plants. The combination of factors $B_2B_3B_6$ gave the least number of lesions—1·8 lesions/sq. cm. against 13·9 on the fully susceptible plants. The average rate of lesion development was significantly decreased by the combinations B_3B_3 and B_3B_6.

9.12. WAY, M. J. (1958). Effects of demeton-methyl on some aphid predators. *Plant Path.* **7**, 9–13.

The systemic insecticide demeton-methyl has proved outstanding as a powerful aphicide which is safer to mammals than demeton or schradan. In Britain it was used extensively in 1957 to stop aphid attacks on many crops and also in attempts to prevent spread of aphid-transmitted virus diseases. Little is known about its possible harm to beneficial insects; field experiments were therefore done to compare its action on some aphid predators with that of parathion, which is known to kill many predators, and schradan, which is virtually harmless to them.

9.13. WAY, M. J. & BANKS, C. J. (1958). The control of *Aphis fabae* Scop. with special reference to biological control of insects which attack annual crops. *Proc. 10th int. Congr. Ent., Montreal* (1956), **4**, 907–909.

Aphidae by their powers of rapid reproduction and efficient dispersal seem well adapted to annual hosts. Chemicals are widely used to control them, but relatively little is known about their control by natural enemies or about the effect of chemicals on this. This paper describes techniques being used in an attempt to evaluate the effects of natural enemies on populations of *Aphis fabae* Scop. Where relevant, chemical and biological controls are compared. First results indicate that, when the aphid is on an annual crop in midsummer, its predators and parasites are a minor factor in its control, and chemical control is necessary if an attack develops. From August to the following May *A. fabae* is on weeds and shrubs often in natural or semi-natural environments. Here, predators and parasites may be a major controlling factor, and hence may determine the number of migrant aphids which in May and June depart to the midsummer host. This is important because the size of the aphid population which develops on the midsummer host and the crop loss are directly related to the number of migrants reaching it.

Insecticides applied to the midsummer host plant deplete the predator population available to attack the aphid on its later hosts. This could have harmful effects.

9.14. WAY, M. J., BARDNER, R., BAER, R. VAN & (AITKENHEAD, P.) (1958). A comparison of high- and low-volume sprays for control of the bean aphid, *Aphis fabae* Scop. on field beans. *Ann. appl. Biol.* **46**, 399–410.

Insecticides were sprayed in different amounts of water to control *Aphis fabae* Scop. attacking spring-sown field beans. The single application of each insecticide was timed to coincide with the end of aphid migration from the winter host to the crop. A tractor-mounted row-crop hydraulic sprayer was used.

In one experiment seven different insecticide sprays were compared at high volume (in 140 gallons of water/acre); the most effective were nicotine at 22·4

oz. of active constituent/acre, demeton at 5·6 oz. and demeton-methyl at 11·2 oz.

A further comparison was made of five insecticides for each of which a selected dose of active ingredient was applied in 60 gallons (medium volume) and in 10 gallons of water/acre (low volume). The amount of insecticide retained on the plant following the low-volume application was not less than that from the medium-volume spray; the efficiency of *A. fabae* control was not affected by the volume sprayed except with malathion, which did better at the medium volume. The systemic insecticide demeton-methyl at 6 oz. of active constituents/acre, the related compound 4741 at 3 oz./acre and fluoroacetamide at 3 oz./acre stopped the aphid numbers from rising above a peak of eight per plant compared with 230/plant for malathion (low volume) at 12 oz.; 2400/plant for lindane at 6 oz., and 3,550/plant for check treatments sprayed with wetter only. Grain yields ranged from around 4 cwt./acre on check treatments to around 27 cwt./acre on plots sprayed once with the systemic insecticides. There was a curvilinear relationship between grain yield and log number of *A. fabae* per plant.

Entomology Department

Book

10.1. Mellanby, K. (1958). *The birth of Nigeria's university.* London: Methuen.

Research Papers

10.2. Banks, C. J. (1957). The behaviour of individual coccinellid larvae on plants. *Brit. J. Anim. Behav.* **5**, 12–24.

The larvae moved on bean leaves, as they did on a flat piece of paper, with frequent changes in direction, but the edges and prominent veins of leaves often determined the pattern of their tracks. The chance touching of leaves of adjacent plants influenced their direction of movement and, when aphid colonies on bean plants were few, larvae might by chance be led far away from them. Coccinellid larvae wasted time and energy in repeatedly visiting parts of plants which they had already visited.

Larvae which encountered aphid colonies tended to stay near them, because after feeding they made small turning movements from side to side, which increased the chance of meeting another aphid of a colony. This behaviour was different from the behaviour before feeding. Fleschner's (1950) conclusion that larvae are unable to perceive the prey from a distance was confirmed.

Larvae (especially the first and second instar) took a comparatively long time to consume aphids and, in the field, one of them was prevented from feeding on an aphid colony by the attacks of ants which were attending them.

The behaviour of larvae is discussed in relation to their survival in the field. It is considered likely that in areas of low prey density many larvae (especially newly hatched ones) die of starvation because they do not find aphids.

10.3. Banks, C. J. (1958). Effects of the ant, *Lasius niger* (L.), on the behaviour and reproduction of the Black Bean Aphid, *Aphis fabae* Scop. *Bull. ent. Res.* **35**, 703–711.

Cage experiments confirmed that, in the absence of natural enemies, populations of *Aphis fabae* Scop., attended on bean plants (*Vicia faba*) by the ant, *Lasius niger* (L.), multiply more rapidly than otherwise similar but ant-free populations. The average difference in numbers recorded was about one-third, the maximum being 70 per cent. No doubling or trebling of aphid numbers as claimed by an earlier worker was ever recorded.

When the aphids are attended by ants, their excretion behaviour alters and the normal dispersal of the apterae from the young apical growth of bean plants is considerably delayed.

No significant differences were found between the numbers of nymphs

produced by individual aphids from ant-visited and ant-free plants, respectively, living on leaves of the same age; but the numbers were significantly affected by the age of the leaf or part of the plant on which the aphids had developed or were then feeding.

It is suggested that ant-attended aphid populations multiply more rapidly because most of the aphids feed for a much longer time on young plant tissue, where, presumably, their food supply is more nutritious.

10.4. Banks, C. J. & Nixon, H. L. (1958). Effects of the ant, *Lasius niger* L., on the feeding and excretion of the Bean Aphid, *Aphis fabae* Scop. *J. exp. Biol.* **35**, 703–711.

Ant-attended aphids excreted twice as much ^{32}P as ant-free aphids did, by increasing their uptake of sap from radioactive broad bean plants. The aphid directly controls its feeding and excretion rates, which are not determined solely by forces within the plant. In the normally feeding aphid, sap uptake, which is apparently not continuous, seems to be regulated by the "sucking pump" in the head.

10.5. Barnes, H. F. (1958). Biosystematics as applied to the Cecidomyidae. *Proc. 10th int. Congr. Ent.* (1956) **1**, 165–170.

An informative account of the methods used at Rothamsted Experimental Station together with the results of testing the identity of a new *Contarinia* pest of Shasta Daisy. It was shown to be *C. chrysanthemi* Kieffer of wild ox-eye daisy.

10.6. Barnes, H. F. (1958). Experimental inter-breeding of Hessian Fly from Kansas, U.S.A., Germany and England. *Z. PflKrankh.* **65**, 333–43.

Hessian fly from the above countries will inter-breed freely, so it is concluded that there is now no reason to doubt that *Mayetiola destructor* (Say) occurs in Europe. Information is given on the occurrence of unisexual families, fecundity, time of day of emergence, and oviposition and the speed of development.

10.7. Barnes, H. F. (1958). The gall midges (Dipt., Cecidomyidae) of Timothy grass inflorescences, with the description of one new species. *Ann. ent. fenn.* **24**, 59–68.

Contarinia kanervoi is described and notes given on its biology. *Stenodiplosis geniculati* of meadow foxtail grass is shown to use Timothy grass as a host plant for its summer generation. The speed of development on its various host plants is discussed. A third injurious species, *Dasyneura* sp., is mentioned, as are an inquiline *Clinodiplosis* sp. and a predacious *Lestodiplosis* sp.

10.8. Barnes, H. F. (1958). A new stem-inhabiting gall midge of *Poa pratensis* (Diptera: Cecidomyidae). *Beitr. Ent.* **8**, 688–692.

A new species from Germany belonging to the genus *Mayetiola* is described as *M. schoberi*.

10.9. Barnes, H. F. (1958). Progress in the biological testing of sorghum midge (*Contarinia* spp.). *Bull. ent. Res.* **49**, 555–558.

Successful emergence of a *Contarinia* species and its parasites have been obtained at Rothamsted Experimental Station from midge-infested heads of sorghum received from India and West Africa. Inter-mating between midges from Ghana and Mysore took place.

10.10. Barnes, H. F. (1958). Wheat Blossom Midges on Broadbalk, Rothamsted Experimental Station, 1927–56. *Proc. 10th int. Congr. Ent.* (1956) **3**, 367–374.

A summary of this 30-year investigation with emphasis laid on the necessity for presampling in order to ascertain the correct date on which to take the main sample for the year, the relationship between the numbers of

larvae and the number of grains shrunken by *S. mosellana* and lost due to *C. tritici*, the periodicity of the two midges and their parasites, and the two periods of cessation of activity exhibited by the larvae.

10.11. Cherry, L. M. (1959). Fat metabolism and temperature acclimatization in the fly, *Phormia terraenovae* R.–D. *Ent. exp. & appl.* **2**, 60–76.

Larvae of the fly *Phormia terraenovae* R.-D. were reared in an insectary at approximately 18° C., and fed on the following foods: yeast/milk, pork, mutton, beef, herring.

When the larvae were fully grown, they were killed and analysed. Larvae from all diets were similar in constitution, except for the Iodine number of the body fat. This varied as follows: milk yeast diet = 62, pork = 70, mutton = 71, beef = 69, herring = 90. The differences between pork, mutton and beef fed larvae were not significant, but the other differences were highly significant.

The differences between the iodine values of the fats in the various foods were greater than those found in the larvae which fed on them (milk yeast = approximately 30, pork = 60, herring = 130).

Larvae reared on mutton at 35° C. contained fat with an Iodine number of 64 (as against 71 for those reared at 18° C.).

The thermal death points for all the larvae reared at 18° C., whatever their diets, were approximately the same. The larvae reared at 35° C. had a thermal death point approximately 1° C. higher.

There appears to be little or no relationship between the composition of the body fat of *Phormia* larvae and their resistance to high temperature.

10.12. Dobson, R. M., Stephenson, J. W. & Lofty, J. R. (1958). A quantitative study of a population of Wheat-bulb fly, *Leptohylemyia coarctata* (Fall.), in the field. *Bull. ent. Res.* **49**, 95–111.

A new method of studying the bionomics of wheat-bulb fly in the field is described. The method combined the use of large field cage with a method of marking and recapture, and daily emergence figures, the rate of population decay and the structure of the population in terms of sex ratios and absolute numbers were investigated. Observations on the populations of the immature stages were also made.

10.13. French, R. A. (1958). Migration Records 1957. *Entomologist*, **91**, 101–109.

10.14. Johnson, B. (1958). Factors affecting the locomotor and settling responses of alate aphids. *Anim. Behav.* **4**, 9–26.

In suitable environmental conditions for flight, alate aphids typically fly from their parent host plants, and they cannot normally be brought to settle down on those or other plants until after they have engaged in flight or other activity. In unsuitable flight conditions they remain on the plants but do not respond to them by feeding and reproducing. Aphids alighting on plants after flight normally spend some time wandering and probing, and they may settle down.

By allowing young alatae of *Aphis fabae* Scop. short tethered and untethered flights of a minimum of 10–20 seconds and then putting them on a leaf surface, it was possible to induce wanderings and probing behaviour. There is evidence that aphids do not normally alight and show this behaviour after being airborne for such a short time, and the behaviour of the aphids in the experiments was probably due to the composite effect of flight and some part of the experimental procedure. Wandering and probing behaviour could also be produced by giving aphids a knockdown dose of CO_2, and by allowing them an extensive period of activity other than flight.

The length of time aphids spent wandering on plants before they took off again, and whether or not they settled down to feed and reproduce, was influenced by the length of flight they had engaged in, the nature of the surface they were released on and the physical environment.

The effect of both short and long flights was soon lost, and in the absence

of strong contralocomotory stimuli, such as darkness or a very suitable host, the aphids reverted to typical locomotory behaviour after showing some degree of the settling response (i.e., wandering and probing or settling down for some time).

Much of the behaviour of alate aphids can be grouped under two opposing general responses—the locomotor response and the settling response; it is suggested that the stimuli determining the type and strength of response of aphids at any time are principally of the same kinds as those which were shown in the experiments to affect the strength of the settling response.

10.15. Long, D. B. (1958). Field observations on adults of the wheat-bulb fly. (*Leptohylemyia coarctata* (Fall.).) *Bull. ent. Res.* **49**, 77–94.

A study of adult populations of wheat-bulb fly, *Leptohylemyia coarctata* (Fall.), has been carried out in the field by routine sweeping at Rothamsted. It has been observed that the males emerge slightly before the females and that the emergence period may cover at least three weeks in late June and early July. Although the number of males may exceed the number of females at first, the females predominate later in the season due to the shorter life span of the males.

The numbers of flies on the wheat have been found to fluctuate appreciably throughout the day. During the first week of the emergence period the number of flies taken increased steadily throughout the day. After the date of population peak, however, the maximum numbers occurred in the crop in the very early morning and the late evening, which suggested a daily flight dispersion followed by a general or localized return of the flies to the crop. Further study of the data showed that the daily temperature rhythm was only partly responsible for this daily flight dispersion, and that there appeared to be an active return flight to the crop in the evening. Generally the males were more active than the females and did not settle so deeply in the crop.

The temperature threshold for flight was observed to be 12°–13° C. Winds up to 8 m.p.h. did not appear to affect flight activity, but higher winds, e.g., 15 m.p.h., markedly reduced flight, the flies remaining deep in the crop near ground level. Gale-force winds, however, were observed to produce a permanent depletion in the number of flies infesting Broadbalk field, indicating that the population was probably localized.

Although portions of the populations dispersed fairly rapidly from the emergence sites, recaptures of radioactive flies labelled with P^{32} indicated that the extent of the dispersions was not very great. The females dispersed more than the males, and were influenced to some extent by the occurrence of wheat in flower. Frequently the flies were found to have congregated on the lee edge of the crop, but other preferred regions have been observed which could not be attributed to the influence of the wind.

10.16. Long, D. B. (1958). Host plant location by larvae of the wheat-bulb fly (*Leptohylemyia coarctata* Fallen). *Proc. R. ent. Soc. Lond.* (A) **33**, 1–8.

The mechanism of host plant location by newly hatched larvae of the wheat-bulb fly has been studied by inoculating pots of prepared young wheat plants and by direct observations of movement in petri dishes.

The results of pot experiments suggest that the larvae move upwards at a fairly steep angle from the egg site and then horizontally in the surface layers of soil. Plant location did not appear to occur as the result of random movements but involved a larval response to attractant material exuding from the plant. The root extremities were not involved in this process, but when roots close to the base of the plant were exposed to the larvae, appreciable infestation of the plants occurred. The highest level of infestation occurred in plants in which the stems only were exposed, indicating that the stems played the major role in the location mechanism and that the attractive root zone may actually interfere with infestation.

The attractiveness of the exudates from the root and stem regions was supported by direct observation of larval movements in petri dishes. Leaf-tip exudates in the form of guttation droplets were also found to be attractive and may, on reaching the soil, reinforce the stem exudates. The attractiveness of the exudates was reduced by boiling.

10.17. Long, D. B. (1958). Observations on the occurrence of larval infestations of wheat-bulb fly, *Leptohylemyia coarctata* (Fall.). *Bull. ent. Res.* **49**, 113–122.

The effect of the previous crop on the subsequent infestation of winter wheat by the wheat-bulb fly, *Leptohylemyia coarctata* (Fall.), mainly on the clay-loam of Rothamsted Experimental Farm has been investigated for the years 1954–56. By far the highest larval populations followed fallows, the next highest potatoes, which are a low, open cover crop, whilst much lower populations followed the tall crops of beans and wheat, and very small infestations followed the grass mat covers. This confirms the results of previous workers under different agricultural conditions.

Previous applications of dung and straw influenced the infestation following fallow in dry summers but not in a wet year. The effects of other manurial treatments were inconclusive.

An experiment designed to determine the effect of the crop density on oviposition was inconclusive, due to the failure to establish an infestation.

Wheat was shown to influence the flight path and to interfere with local egg-laying behaviour, producing a horizontal effect of up to twice its own height.

Apart from the foregoing factors at Rothamsted, where the wheat fields are well separated, the differences in the level of infestation that were observed could be explained by close proximity or otherwise to a centre of heavy fly infestation.

Reasons are put forward for suggesting that the effect of the previous crop on oviposition may be interpreted in terms of the opportunity existing for contact with the soil rather than as a preference on the part of the fly.

10.18. Long, D. B. (1958). Observations on oviposition in the wheat-bulb fly, *Leptohylemyia coarctata* (Fall.). *Bull. ent. Res.* **49**, 355–366.

In laboratory cultures of wheat-bulb fly, *Leptohylemyia coarctata* (Fall.), a daily oviposition rhythm was observed in which egg-laying was virtually restricted to the afternoon and evening with maximum laying occurring in the two hours before nightfall. The time of oviposition coincided with that part of the diurnal flight rhythm, earlier observed, in which the flies actively congregated on wheat, and this, it is suggested, could account for the fact, already recorded, that laying has been found to occur mostly on sites close to an infested crop.

The oviposition rhythm was maintained for 24 hours in absence of light, and therefore appeared to be partly inherent. However, it could be influenced by the times of exposure to light and disappeared in constant light. Darkness did not appear to affect the egg-laying rate, but a temporary increase followed exposure to continuous light. Within the course of the experiments the rate was not affected by small changes in temperature.

The individual fly laid up to 180 eggs in the laboratory in periodic batches of up to 42 eggs laid over periods of 1–6 days. This periodicity was obscured in cages containing a number of flies. Disproportionately small decreases in the mean daily laying rate occurred with increases in this laying period. Within the laying period the rate progressively increased with each successive day. The total number of eggs laid was not related to the number of ovarioles. In the laboratory the rate of laying increased with age and most of the eggs were laid by relatively few flies.

The rate of egg-laying and survival at different stages in the field is discussed and it is suggested that about 2 per cent of the eggs successfully develop as matured females which lay an average of about 50 eggs each.

10.19. Long, D. B. & Zaher, M. A. (1958). Effect of larval population density on the adult morphology of two species of Lepidoptera, *Plusia gamma* L. and *Pieris brassicae* L. *Ent. exp. & appl.* **1**, 161–173.

The morphological effects of population density in locusts in the production of " phases " is now well established, and in recent years somewhat parallel effects have been observed in the larvae of Lepidoptera. Unlike locusts, Lepidoptera pass through a quiescent pupal period, but nevertheless the adult

may be affected. In both *P. gamma* and *P. brassicae* adults from crowded larval cultures were smaller in both size and weight, although the effect was counteracted to some extent by approaching pupal diapause in *P. brassicae*. The effect was similar in many cases to that produced by an increase in temperature, except that it disturbed the relationships between the lengths of the wing and hind femur with the live weight. The ratio of these lengths (equivalent to E/F ratio in locusts) was significantly increased, but was not a satisfactory index of larval population density. No effects were observed in the wing pattern and coloration in either species.

10.20. MELLANBY, K. (1958). The alarm reaction of mosquito larvae. *Ent. exp. & appl.* **1**, 153–160.

The alarm reaction in three species of mosquito larvae has been investigated.

All larvae disappear from the surface of the water when " alarmed ", but the mechanism of the reaction differs in the different species. *Aedes aegypti* is lighter than water. It swims actively to the bottom, and returns passively to the water surface by floating upwards. *Culex* and *Anopheles* larvae are heavier than water. They sink passively to the bottom when alarmed; return to the water surface is an active process, necessitating swimming by the larvae.

Repeated stimulation produces " stimulus-satiation ". When a larva ceases to react to one stimulus (e.g., vibration) it will react immediately to another (e.g., light), which suggests that the sensory receptors become adapted but that the effector muscles are not fatigued.

After stimulation *Aedes* larvae are negatively phototactic. They are also positively geotactic, but the phototaxis is the stronger reaction. *Culex* and *Anopheles* relax when " alarmed " and, in this condition, they sink passively in the water; they do not react to changes in light intensity.

The chill coma temperature is several degrees cooler than the lowest temperature at which the alarm reaction takes place. Acclimatization, which takes under 24 hours, can alter the position of both the chill coma temperature and that at which the alarm reaction takes place.

10.21. MELLANBY, K. (1958). Water content and insect metabolism. *Nature, Lond.* **181**, 1403.

10.22. MELLANBY, K. (1958). Water drinking by the larva of the European Corn Borer. *J. econ. Ent.* **51**, 744–745.

Larvae, after their winter diapause, drink water and resume activity. They do not absorb water through the cuticle, as was previously believed.

10.23. MELLANBY, K. & FRENCH, R. A. (1958). The importance of drinking water to larval insects. *Ent. exp. & appl.* **1**, 116–124.

Many insect larvae have been found to drink water. These include larvae inhabiting stored products, phytophagous species, larvae found in the soil and species dehydrated during diapause. The water taken in may enable the larvae to withstand unfavourable conditions.

10.24. MURPHY, P. W. (1958). The quantitative study of soil meiofauna. I. The effect of sample treatment on extraction efficiency with a modified funnel extractor. *Ent. exp. & appl.* **1**, 94–108.

Construction details of the split-funnel extractor, a modified funnel method for extracting soil fauna are given, together with results of an experiment to test the apparatus, and the effect of sample treatment on extraction of Acarina from heathland samples.

10.25. MURPHY, P. W. (1958). The quantitative study of soil meiofauna. II. Sample preparation and routine methods for handling the catch. *Ent. exp. & appl.* **1**, 109–115.

Details of a method for preparation of undisturbed samples for extraction with a modified funnel are given, together with techniques for the quantitative assessment of the catch (especially Acarina and Collembola). These techniques include handling, visual examination and storage of the fauna.

10.26. Murphy, P. W. (1958). Soil faunal investigations. *Rep. For. Res.* for 1957.

10.27. Raw, F. (1959). An insectary method for rearing the cacao Mirids *Distantiella theobroma* (Dist.) and *Sahlbergilla singularis* (Hagl.). *Bull. ent. Res.* **50**. (In the press.)

Adults are caged for oviposition on cacao seedlings grown in baskets. When the eggs hatch the nymphs are transferred to, and reared on, unripe cacao pods suspended in ventilated glass cages.

10.28. Raw, F. (1959). Studies on the chemical control of the cacao Mirids *Distantiella theobroma* (Dist.) and *Schlbergilla singularis* (Hagl.). *Bull. ent. Res.* **50**. (In the press.)

Laboratory and field tests were made to investigate the toxicity, mode of action and persistence of DDT and BHC when applied to cacao to control the mirids *Distantiella theobroma* Dist. and *Sahlbergilla singularis* Hagl. Preliminary tests with aldrin, chlordane and dieldrin were also made.

BHC had a higher toxicity and acted much quicker than DDT. It also greatly reduced feeding. BHC had a powerful but transient fumigant action. DDT had no fumigant action. In field tests DDT persisted longer than BHC, but was probably ineffective after 3–4 weeks. Some results suggested that BHC had a local systemic action.

It was concluded that BHC would be more effective than DDT when treating mature cacao because, in addition to its higher toxicity and quicker action, its fumigant action would compensate for incomplete coverage by low-volume spraying.

Of the other insecticides tested, aldrin had a high toxicity and fumigant action and appeared to be the most promising alternative to BHC.

10.29. Stephenson, J. W. (1958). *The biology of* Brachydesmus superus *Latz.* (M.Sc. thesis, University of London.)

10.30. Stokes, B. M. (1958). Hessian fly on Rothamsted Farm. *Plant Path.* **7**, 22–24.

Wheat on Broadbalk field and on Hoosfield at Rothamsted Farm was sampled in 1954, 1955 and 1956. Infestation of straws ranged from 5·8 to 1·3 per cent, and of tillers from 42·3 to 0·0 per cent. No statistically significant differences between years or plots were found.

10.31. Stokes, B. M. (1958). The worm-eating slugs *Testacella scutulum* Sowerby and *T. haliotidea* Draparnaud in captivity. *Proc. malac. Soc. Lond.* **33**, 11–20.

Specimens of *Testacella scutulum* Sowerby and *T. haliotidea* Draparnaud were kept in jars in captivity and observed daily for over a year. They were weighed each week, and records were kept of the numbers of worms they ate. Mating, oviposition and the hatching of eggs were seen. Data were obtained on the feeding and growth rates of the young slugs.

10.32. Way, M. J. & Banks, C. J. (1958). The control of *Aphis fabae* Scop. with special reference to biological control of insects which attack annual crops. *Proc. 10th int. Congr. Ent.* (1956), **4**, 907–909.

For summary see above, p. 261, no. 9.13.

Bee Department

Book

11.1. Free, J. B. & Butler, C. G. (1959). *Bumblebees.* (New Naturalist Series.) London: Collins.

General Papers

11.2. Bailey, L. (1958). Wild honeybees and disease. *Bee World*, **39**, 92–95.

11.3. Butler, C. G. (1958). Queen supersedure and swarming. *Rep. cent. Ass. Brit. Beekeep. Ass.*

11.4. Butler, C. G. (1959). Sex determination and caste differentiation in the honeybee (*Apis mellifera*). *Mem. Soc. Endocrinol.* 7. (In the press.)

11.5. Free, J. B. (1958). The behaviour of honeybees when their hive is moved to a new site. *Bee World*, **39**, 109–115.

11.6. Free, J. B. (1958). The production of egg-laying workers in bumblebee colonies. *Insect. Soc.* (In the press.)

11.7. Free, J. B. (1958). The transfer of food between the adult members of a honeybee community. *Insect. Soc.* (In the press.)

11.8. Simpson, J. (1958). The problem of swarming in beekeeping practice. *Bee World*, **39**, 193–202.

Research Papers

11.9. Bailey, L. (1958). The epidemiology of the infestation of the honeybee, *Apis mellifera* L., by the mite *Acarapis woodi* Rennie, and the mortality of infested bees. *Parasitology*, **48**, 493–506.

Transmission of infection to young honeybees was facilitated, in laboratory experiments, by increased temperature and increased infection of old infected bees, and, in field experiments, by inactivity of foraging bees. Mortality of infected bees was only slightly greater than of those uninfected. Colonies with more than 30 per cent of bees infected were more likely to die than uninfected colonies, and those with more than 75 per cent of bees infected were certain to die; but few colonies became so heavily infected. Death always occurred in late winter.

11.10. Butler, C. G. & Simpson, J. (1958). The source of the queen substance of the honeybee (*Apis mellifera* L.). *Proc. R. ent. Soc.* (*A*), **33**, 120–122.

It is shown that the contents of the mandibular glands of a mated queen honeybee, but not of a worker bee, are capable of inhibiting queen production by queenless worker honeybees. No such effect was produced by the haemolymph of a queen or by crushed brain or ovaries. It is concluded that the mandibular glands of the queen honeybee produce queen substance.

11.11. Free, J. B. (1958). The ability of worker honeybees (*Apis mellifera*) to learn a change in the location of their hives. *Anim. Behav.* **6**, 219–223.

When the site of a colony of honeybees was changed, and other colonies were put near the old site, nearly all the bees which returned there from the new one attempted to join them. When there were no colonies near to the old site, 69–100 per cent of the bees returned to their colony in its new position, although many of them visited the old site first. Some bees also visited the old site on subsequent occasions; the behaviour of the individual bees varied greatly.

The proportion of bees visiting the old site depended on the distance between old and new sites, and decreased with increase in the distance their colony had been moved. The greater the distance between old and new sites, the longer bees spent at the old site before returning to the new one, and the less likely they were to return to the new one.

11.12. Free, J. B. (1958). Attempts to condition bees to visit selected crops. *Bee World*, **39**, 221–230.

The literature dealing with attempts to condition bees to visit selected crops and the techniques employed are briefly reviewed.

In the experiments described attempts were made to direct bees to visit crops of apple and red clover. The results were ascertained by comparing the percentage of pollen from the crop concerned which was collected by the "directed" and control colonies. No beneficial effect of directing was apparent, and it is considered that more conclusive results are desirable before the practice of directing bees to crops can be recommended in Britain.

11.13. Free, J. B. (1959). The drifting of honeybees (*Apis mellifera*). *J. Agric. Sci.* **51**, 294–306.

The majority of bees that drift do so during orientation flights before they become regular foragers. Bees emerging in August and September drift less than those emerging earlier in the year. The amount that bees drift varies considerably in different circumstances, and may be very great. Drones drift two or three times as much as workers.

Proportionately more bees drift from small to large colonies than *vice versa*, but the greater number of bees flying from the large colonies results in a net gain in bees by the smaller ones.

When hives are arranged in repetitive patterns, bees drift to hives occupying similar positions in other patterns to the ones their hives occupy in their own pattern. When hives are arranged in rows, bees from the central colonies drift more than those at the ends, resulting in the latter colonies gaining numerically. In some circumstances more bees drift to hives in one direction than in the opposite one. If hives are arranged to face in different directions, and are painted different colours, drifting is considerably reduced. The facing of the hives in different directions reduces drifting more than painting them different colours.

11.14. Free, J. B. & Butler, C. G. (1958). The size of apertures through which worker honeybees will feed one another. *Bee World*, **39**, 40–42.

If bees are to feed one another through the apertures in wire-gauze these need to be considerably larger than the cross-section of a bee's tongue, since feeding will only take place if antennal contact is possible. It is concluded that apertures of not less than 2·5 mm. square are desirable in wire-gauze used in the construction of queen cages.

Statistics Department

General Papers

12.1 Church, B. M. (1959). The uses of fertilizer practice surveys and appropriate survey techniques. *FATIS Rev.* (In the press.)

12.2. Yates, F. (1959). The introduction of electronic computers in research statistics. *Rep. agric. Res. Coun.* for 1957/58.

12.3. Yates, F. (1958). Second Report to the Government of India on statistics in agricultural research. *F.A.O. Rep.* 987.

Research Papers

12.4. Boyd, D. A. (1959). The effect of farmyard manure on fertilizer responses. *J. agric. Sci.* (In the press.)

Farmyard manure affected the response of the potato crop to fertilizers similarly in seven series of experiments (sixty-two in all) at Rothamsted, and in the West Midlands and north of England.

In the absence of FYM there were large interactions between each of the fertilizer nutrients, but with FYM the interactions were small. These interactions appear to have been ignored by previous workers, who claimed that nitrogen responses are unaffected by dressings of FYM. In fact, FYM increased the response to nitrogen applied alone, but decreased the nitrogen response where basal P and K fertilizers were also applied. For phosphate the results were similar to those for nitrogen.

Most of the experimental sites were low in potash, and potash responses were very large, especially in the presence of basal NP fertilizer. Farmyard manure greatly reduced the response to potash, particularly in the presence of basal NP fertilizer.

Rothamsted experiments testing FYM and fertilizers and several times of planting showed that the large responses to FYM alone and to fertilizers used in combination (but without FYM) were not reduced by late planting. The result conflicts with previous reports of these data, in which interactions between nutrients were ignored. The combined effect of FYM and fertilizers at late planting was little more than their separate effects, presumably due to delayed maturity, the influence of which would be exaggerated by the early burning-off of haulm in this series of experiments.

Most of the experiments were limited to testing fertilizers at two levels (presence and absence), so the effective quantities of nutrients provided by FYM for the crop to which it was applied could only be estimated approximately; the average amounts suggested for normal FYM are 0·3 cwt. N, 0·4 cwt. P_2O_5 and 0·75 cwt. K_2O in 10 tons FYM.

These results lead to the practical conclusion that, in manuring potato crops on average land, much the same plant food ratios will be appropriate whether or not FYM is given, and the amount of fertilizer applied can be decreased to allow for the nutrients contained in the FYM.

12.5. Church, B. M. (1958). Report to the Government of Ethiopia on the development of agricultural statistics. *F.A.O. Rep.* 889.

This report was prepared on the termination of a 15-month assignment to Ethiopia under the auspices of the Food and Agriculture Organization of the United Nations. The purpose of the assignment was to assist the Government in initiating a system of current agricultural surveys and censuses, particularly by setting up pilot surveys to test appropriate sampling methods and by the training of field and office personnel.

A programme for the development of an agricultural statistics service is outlined, and attention is drawn to specific survey and pilot investigations which should be undertaken as the organization is being built up. Surveys of the Addis Ababa milk supply, a general survey of livestock in semi-nomadic regions of southern Ethiopia and a pilot survey of land utilization and cropping undertaken during the assignment are briefly described.

12.6. (Fidler, J. H.), Church, B. M. & (Southey, J. F.). (1959). Field sampling and laboratory examination of cereal-root eelworm cysts. *Plant. Path.* (In the press.)

Co-operative sampling experiments undertaken by the Advisory Entomologists are described. The sampling errors of estimated cyst population densities, due to within-field heterogeneity and due to laboratory examination are estimated. Laboratory examination of 200 gm. soil taken from a well-mixed bulk sample of 2,500–5,000 gm. obtained from 50 or so randomly located points in a field normally provides an estimate of sufficient accuracy for advisory purposes. Recommendations are made for uniformity in details of laboratory technique.

12.7. Gower, J. C. (1958). A note on an interative method for root extraction. *Comp. J.* **1**, 142.

A double iterative method for evaluating $y/x^{1/n}$ is derived, and it is shown that if $-1 \leqslant y^n < x < 1$, then it can be arranged that all terms occurring in the iteration are also within this range. The rate of convergence is then discussed and some special cases are mentioned.

12.8. GOWER, J. C. & RAYNER, J. H. (1958). Crystallographic programmes for the Elliott-N.R.D.C. 401 computer. *Brit. J. appl. Phys.* **9**, 446.

A brief description is given of programmes for the calculations involved in the X-ray analysis of crystal structures. The programmes calculate three-dimensional structure factors, one- and two-dimensional Fourier syntheses and R-factors.

12.9. HEALY, M. J. R. (1959). The effect of age-grouping on the distribution of a measurement affected by growth. *Amer. J. phys. Anthrop.* (In the press.)

Consider a measurement which is normally distributed at a fixed age and whose mean and variance increase linearly with age over a short period such as 1 year. If measurements taken over the whole period are pooled, the resulting distribution has the same mean as that of measurements taken at the central age, but the variance and higher cumulants are altered. Formulae are given relating the "pooled" values of the first four cumulants to the "instantaneous" values. The correction may be of importance in setting up standards of growth achieved at different ages.

12.10. HEALY, M. J. R. (1958). Variations within individuals in human biology. *Hum. Biol.* **30**, 210–218.

When a measurement on an individual is repeated, the two results do not usually agree exactly. The difference may result from inadequacy of the measuring technique or from real changes in the quantity measured. The paper discusses the assessment of this within-individual variation and its effect on estimates of variances, regression coefficients and correlations.

12.11. HEALY, M. J. R. (1959). Some basic statistical techniques in soil zoology. *Proc. int. Colloq. Soil Zool.* (In the press.)

This paper outlines a number of the basic techniques that are of use in soil zoological investigations. The general nature of statistical arguments is explained, and methods are described for estimating populations of soil animals, for investigating spatial distributions and for analysing counts from field experiments.

12.12. HEALY, M. J. R. (1959). Statistical Appendix to "A longitudinal study of the results of premature extraction of deciduous teeth between 3–4 and 13–14 years", by L. M. Clinch. *Dent. Practit.* (In the press.)

Successive annual measurements were taken on the dental arches of a number of children over the age range 3–4 to 13–14 years. Premature extraction of deciduous teeth is shown to result in a marked decrease in the width of the premolar-molar segment. The total space loss is related to the initial spacing between the teeth and, in the lower jaw, to the breadth of the permanent teeth.

12.13. LEECH, F. B. & HEALY, M. J. R. (1958). The analysis of experiments on growth rate. *Biometrics.* (In the press.)

A method is presented for the analysis of experiments in which successive measurements of the same quantity on the same organism are made at equal intervals of time. The specification and estimation of treatment effects are discussed, and the method is applied to an experiment on the growth rate of pigs.

When a treatment effect of degree p is specified, curves of degree p are fitted to the observations and it is shown that two estimates of each coefficient of the treatment effect are obtained from functions of the coefficients of these curves. The method of combining these estimates with minimum variance is shown. Thus when the treatment effect is linear in time, straight lines are fitted to the data and two estimates are obtained. A minimum variance combination of these gives an improved estimate of the treatment effect. The use of covariance analysis on the initial observations is also discussed.

12.14. LEECH, F. B. & (SELLERS, K. C.) (1958). A second survey of losses associated with pregnancy and parturition in Yorkshire sheep. *J. agric. Sci.* (In the press.)

The results, as judged by returns for losses were similar to those observed in the first survey (Sellers & Leech, 1955), but the extra detail on the new questionnaire allowed a more critical analysis of some of the various categories of loss.

The results obtained are too numerous for an abstract, but two items of unusual interest were discovered. On arable farms the rate of abortion was 2·3 times greater in ewes bearing two or more foetuses than in ewes bearing a single foetus. There was no such differential rate under other forms of husbandry. The second item was a lower incidence of still-births than expected in ewes bearing two or more foetuses but not getting hay during pregnancy. Explanations of these results are offered which the authors suggested might be tested experimentally.

12.15. (LESLIE, P. H.) & GOWER, J. C. (1958). The properties of a stochastic model for two competing species. *Biometrika*, **45**, 316.

A stochastic model for studying by numerical methods the properties of the population variations of two competing species is described. Two varieties of this model have been programmed for the Elliott-N.R.D.C. 401 Computer in the Statistical Department at Rothamsted Experimental Station, and some of the results are given in the paper, together with a discussion on how these results are related to Parks' experimental observations on *Tribolium castaneum* and *Tribolium confusum*.

12.16. LIPTON, S. (1958). The evaluation of the bi-variate normal integral over a particular non-rectangular region. *Proc. Int. Congr. Mathematicians*, Abstracts of Short Communications, 1958, 161.

The integral of the bivariate normal distribution over an area defined by two exponential-type curves, arises in the development of a unified theory for quantal responses to drugs (Hewlett & Plackett, 1957, Nature, **180**, 712).

A method is described for evaluating this double integral using an empirical formula (due to C. Hastings, Jr.) for the uni-variate normal integral and Weddle's formula for the final integration. The merits of such empirical formulae and the steps taken to maintain accuracy and speed are briefly discussed.

The results, which were obtained using an electronic computer, were spot-checked with the help of a graphical method which yielded surprisingly high accuracy.

12.17. PATTERSON, H. D. (1958). The use of autoregression in fitting an exponential curve. *Biometrika*. (In the press.)

The simple regression of y_{x+1} on y_x has sometimes been used as an estimate of ρ in the equation

$$y_x = \alpha - \beta\rho^x$$

where $0 < \rho < 1$, $x = 0, 1, 2 \ldots n - 1$ and y_x are subject to independent errors with equal variance. An investigation by Dr. D. J. Finney, described in the same issue of *Biometrika*, showed that the estimate is of high efficiency and subject to a relatively small bias when $n = 4$. The present paper deals with the behaviour of the estimate for larger n. As n increases, the efficiency decreases markedly over the useful range of ρ, and the estimate is subject to an increasingly large negative bias. These properties invalidate the estimate.

Alternative estimates given by the regression of y_{x+1} on $ky_x + ly_{x+1}$ have also been considered. These estimates have the same asymptotic efficiency as the simple regression, but by a suitable choice of k/l the bias can be considerably reduced. They are, however, of only limited value, since in practice choice of k/l is difficult unless n is small.

The methods used to investigate the regression of y_{x+1} on y_x are suitable for a wide class of " quadratic " estimates of ρ (estimates of ρ in the form of a ratio of two quadratic functions of the y_x) defined in the paper.

12.18. PATTERSON, H. D. & (LUCAS, H. L.) (1958). Extra-period change-over designs. *Biometrics*, **15**. (In the press.)

This paper deals with extra-period designs obtained by repeating the treatment pattern of the last period of any design in a general class of basic change-over designs. The basic designs are derived from Latin squares or incomplete Latin squares, and satisfy certain conditions of balance which facilitate the estimation of direct and first residual effects. The construction, analysis, efficiencies and uses of the extra-period designs are discussed in some detail.

12.19. (REEVE, E. C. R.) & GOWER, J. C. (1959). The effects of inbreeding when selection acts against homozygosis at one or more loci. *Proc. int. Symp. Biometr. Genet.* (In the press.)

Selection against homozygotes at certain loci is probably of general occurrence in normally outbreeding species, and will reduce the rate of progress towards homozygosity when such a species is inbred. A realistic theory of inbreeding must therefore take into account such effects.

Selection acting at a single locus will have both a direct effect on the speed of inbreeding at this locus and also indirect effects, through linkage, on points near it on the same chromosome. The direct effects have been investigated theoretically for all the standard inbreeding systems, but mathematical formulation of the linkage effects leads in most cases to very large generation matrices.

The simplest sib-mating case—equal selection against both homozygotes at one locus and its effect on a linked locus—which gives a 19×19 matrix, has been analysed with the help of an electronic digital computer, and the results are here compared with the corresponding situation under selfing.

A given selection pressure causes a relatively greater reduction in inbreeding speed at the locus directly affected, under sib-mating than under selfing, but the linkage effects are dispersed more rapidly as we move away along the chromosome, under sib-mating. This means that selection at one point on a chromosome has an effect which is locally more severe, but is also more localized in terms of the length of chromosome affected, under a milder than under a more rapid system of inbreeding.

Analysis of the effects of linkage to two loci each carrying only recessive lethals, in the two systems, suggests that selection against homozygosity at several points on the same chromosome will tend to sharpen the differences in inbreeding speed between different systems in the neighbourhood of these points, and to lessen these differences at loci in intermediate regions.

12.20. (SPICER, C. C.) & LIPTON, S. (1958). Numerical studies on some contagious distributions. *J. Hyg. Camb.* **56**, 516–522.

A numerical investigation of three contagious distributions of epidemic data has been made using an electronic computer. All three show a modified threshold effect such that the proportion of a community affected tends to 100 per cent as its size increases, though there is no abrupt change of form.

12.21. WESTMACOTT, M. H. (1958). Rearing dairy heifers on different planes of nutrition: an interim report on three experiments. *Exp. Husb.* (In the press.)

Three experiments on the rearing of autumn-born heifers are described, and tables of growth rates and body weights up to 2 years of age are presented.

A moderate plane of nutrition in the first and/or second winter of the life of the heifers depressed conception rates at 15 months old compared with a high plane of nutrition; after a further year there was little difference between conception rates. In general, it was the lighter animals in each treatment group which failed to conceive.

12.22. YATES, F. & REES, D. H. (1958). The use of an electronic computer in research statistics: four years' experience. *Comp. J.* **1**, 49–58.

An electronic computer has now been in operation for four years in the Statistics Department of Rothamsted Experimental Station. This paper gives an account of the experience gained in applying the computer to statistical problems arising in agricultural and biological research.

12.23. (Blood, J. W. *et al.*), Boyd, D. A., Church, B. M., Hills, M. G. & Simpson, H. R. (1958). The survey of fertilizer practice, 1957. Part II. (Ministry of Agriculture Duplicated Report.)

12.24. Boyd, D. A. & Lessells, W. J. (1958). The N.A.A.S./N.I.A.B. variety trials 1955–57: the effect of nitrogen and its interaction with variety. Preliminary report.

12.25. Boyd, D. A. (1958). Field experiments on the correlation of soil analysis with crop response to fertilizers. First and Second Reports.

12.26. (Yeo, D.) & Simpson, H. R. (1958). The effect of repeated insecticidal applications on a natural tsetse population. *Colon. Pesticides Res. misc. Rep.* 207.

Woburn Experimental Station

15.1. Mann, H. H. (1958). Effect on yield of undersowing winter grain. *Agriculture, Lond.* **65**, 419–420.

In an experiment at Woburn, there was little difference in the crops of grain (winter wheat and winter rye) when undersown with a clover seeds mixture, as compared with similar grain crops when not undersown.

15.2. Mann, H. H. (1958). Field studies in green manuring. I. *Emp. J. exp. Agric.* **26**, 274–282.

In experiments carried out for 6 years on light soil at Woburn, comparisons were made between lupins, vetches and mustard as green manure crops. The effects of removing the whole crop, or burying the roots only, or burying whole plants, or burying whole plants plus extra tops, were measured by the yield of a kale crop grown immediately after burying the green manure crop.

Green-manure crops had appreciable manurial value when utilized at once. It is important, therefore, that the crop which is intended to benefit should be grown very soon after the green manure is buried in soil conditions favourable for its rotting.

Beneficial results were not directly related to the amount of nitrogen, nor of organic matter in the buried material. There is some relationship in each case, but it is complex and obscure. Little or no benefit resulted from growing a green crop and then removing it, or from leaving only the roots. Burial of the whole crop, with or without extra tops, gave similar beneficial results with both legumes, but the effects with mustard were variable.

15.3. Mann, H. H. (1959). Field studies in green manuring. II. *Emp. J. exp. Agric.* (In the press.)

An account is given of investigations continued at Woburn with the object of determining the factors which control the efficiency of green manures. Relevant factors studied were the effects from additions of farmyard manure, or straw, or nitrogenous fertilizers applied when the green manures were buried. The green manures used were either grown in the spring (vetches, lupins, mustard, rape), or undersown in the previous crop of barley (clover, ryegrass). In all cases, the green-manure crop was buried by ploughing, in June or July, and followed almost at once by the sowing of kale or the planting of winter cabbages, which served as test crops.

Earlier results were confirmed, in so far as the immediate effect of a green manure was not to any great extent determined by the amount of green matter buried, but there was a remote connection between the amount of nitrogen buried and the efficiency of the green manure.

The addition of farmyard manure to the green manures did not materially affect their efficiency, whilst the addition of straw was disadvantageous.

Additions of nitrogenous fertilizer at time of burial increased the efficiency of the green manures.

After a period of 18 years, the effects on nitrogen and organic-matter status of the soil were greater in the cases of those green manures which were undersown in the previous crop of barley.

Dunholme Field Station

General Papers

16.1. Adams, S. N. (1958). Sugar-beet fertilizer experiments in 1957. *Min. Agric. Sug. Beet Res. & Educ. Comm. Pap.* **489**.

16.2. Byford, W. J. (1958). *Phytophthora verrucosa* on Dahlia. *Plant Path.* **7**, 38.

16.3. Cornford, C. E., Dunham, E. C. W., Dunning, R. A., Gates, L. F. & Hull, R. (1958). Sugar-beet disease investigations, 1957–58. *Min. Agric. Sug. Beet Res. & Educ. Comm. Pap.* **486**.

16.4. Cornford, C. E. (1958). Oospores of *Peronospora schachtii* found in England. *Plant Path.* **7**, 38.

16.5. Cornford, C. E. (1958). Perfect stage of *Phoma betae* found in England. *Plant Path.* **7**, 113.

16.6. Hull, R. (1958). Sugar-beet yellows in Great Britain, 1957. *Plant Path.* **7**, 131.

16.7. Hull, R. (1958). Sugar-beet yellows. The search for control. *Agriculture, Lond.* **65**, 62–65.

16.8. Hull, R. (1958). Sugar Beet. A crop in peril. *Fmrs Weekly*, **48**, Sugar Beet & Potato Suppl., 13–14.

Research Papers

16.9. Dunning, R. A. (1957). Stem eelworm invasion of seedling sugar-beet and development of crown canker. *Nematologica*, **2** (Suppl.), 362–368.

Literature on the host range of the race of stem eelworm concerned, the symptoms of crown canker, effect on yield and the distribution of attacks in Europe is reviewed. Serious attacks most often develop as a result of eelworms from the soil invading seedlings. The infested seedlings show distinct symptoms. When invaded early they become " blind " and later grow into multiple-crowned plants. Severe canker develops in the autumn in plants invaded as seedlings. Slight canker can develop when plants are invaded during the summer and early autumn. Mangolds are more susceptible than sugar beet to eelworm invasion and to canker.

16.10. Gates, L. F. (1958). Experiments on black leg disease of sugar-beet seedlings. *Ann. appl. Biol.* **47**.

Soaking sugar beet seed for 20 minutes in ten times its weight of water containing 40 p.p.m. ethyl mercury phosphate to control seed-borne *Phoma betae* gave better seedling emergence than surface treatments with commonly used organo-mercury dusts or with " Panogen ", thiram, " Granosan M ", " Captan ", " Dow 9B " or " Cerenox ". In 4 years' field trials, soaking seed in ethyl mercury phosphate solution, followed by dusting with an insecticidal dust, compared with a routine, combined mercury plus insecticidal dust, increased seedling emergence at fifty-three of fifty-nine sites by an average of 10 per cent under good emergence conditions and by 20–30 per cent under adverse conditions. Final plant stand was increased each year by an average of 5·8, 3·4, 1·8 and 0·6 per cent respectively.

16.11. Gates, L. F. (1958). Seed and soil treatment with systemic insecticides to prevent aphid colonisation of emerging sugar-beet seedlings. *Ann. appl. Biol.* **47**.

When 2 lb. "Hanane" or 1 lb. "Thimet" were applied at drilling in 100 gallons water along the drills, or seed was treated at rates to apply 6–8 oz. "Thimet" or 8–24 oz. "Disyston"/acre, sugar-beet seedlings were toxic to aphids 30 days after planting four April–May-sown root crops, and 30–40 days after planting five autumn-sown steckling crops. Germination was 73–100 per cent after soil treatments, 91–98 per cent after "Disyston" seed treatments and 62–84 per cent after "Thimet" seed treatments. The treatments slightly reduced *Aphis fabae* injury to stecklings in 1955 and the number of plants with yellows in a steckling experiment in 1956.

Soil Survey of England and Wales

17.1. *The county of Anglesey—soils and agriculture.* London: H.M. Stationery Office, 1958.

17.2. *Soil map of the Lleyn Peninsula. Sheet 119* (7th Edn.). Southampton: Ordnance Survey, 1958.

17.3. Ashley, G. D. & Wilkinson, B. (1958). Observations on restored opencast coal sites. *N.A.A.S. quart. Rev.* (In the press.)

17.4. Osmond, D. A. (1958). Micropedology. *Soils & Fert.* **21**, 1–6.

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Catalogue of serial publications in the Library, 1953. Edited by D. H. Boalch. (Rothamsted, 1954; 17/6.)
Catalogue of serial publications in the West Building Library at Rothamsted (Entomology, Insecticides, Mycology), March, 1956. Edited by D. H. Boalch. (Rothamsted, 1956; mimeographed; 2/-.)
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Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection, by D. H. Boalch. (Rothamsted, 1958; one guinea.)

* Out of Print.

Books by Present and Past Members of the Rothamsted Staff

*1911 HALL, Sir A. D. & RUSSELL, Sir E. J. A report on the agriculture and soils of Kent, Surrey and Sussex. London: H.M.S.O.

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SOIL	Well drained. flinty loam (originally acid) on clay subsoil overlying chalk
ELEVATION	350'– 430' above sea level
ANNUAL RAINFALL	28·45 inches
ACREAGE	603 acres

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Broadbalk	Continuous Wheat since 1843
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Park Grass	Continuous Hay since 1856
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